Enhancing Crowd Evacuation and Traffic Management Through AmI Technologies: A Review of the Literature

Eve Mitleton-Kelly, Ivan Deschenaux, Christian Maag, Matthew Fullerton, and Nihan Celikkaya

1 Introduction

This document is a review of the burgeoning literature on the utilisation of AmI (Ambient Intelligence) technology in two contexts: providing support and enhancing crowd evacuation during emergencies and improving traffic management.

The review opens with a brief introduction to the field of AmI, which emerged as a synthesis of several prior areas of research. A list of key elements for a definition of AmI is established, and the opening section ends with a survey of some recent contributions concerning the direction of future research on AmI, as well as some of its important, non-emergency related applications, to provide the broader context of AmI research and application.

The following section turns to the utilisation of AmI technologies for the improvement of evacuation during disasters and emergencies. It is worth emphasising that this is both a specialised and recent field of research. The earliest publications we found that make more than anecdotal mention of AmI's potential for improving evacuation date back only to the 2000s. Earlier research on crowd evacuation, sensor networks, and computing does exist, but it rarely uses the term 'AmI' explicitly. Indeed, this terminological issue is important: there are forms of research which operate under assumptions similar to those of AmI, yet do not use

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E. Mitleton-Kelly (✉) • I. Deschenaux
The London School of Economics and Political Science, Complexity Research Group,
London, United Kingdom
e-mail: e.mitleton-kelly@lse.ac.uk

C. Maag
University of Wurzburg (on traffic), Würzburg, Germany

M. Fullerton • N. Celikkaya
Technical University of Munich (TUM) (on traffic), Munich, Germany

E. Mitleton-Kelly (ed.), *Co-evolution of Intelligent Socio-technical Systems*,
Understanding Complex Systems, DOI 10.1007/978-3-642-36614-7_2,
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the same denomination.[1] We distinguish two types of research: that which uses AmI as a technology for crowd monitoring, and that which uses AmI to modify crowd behaviour. There is some overlap between these types, and we found in particular that research of the latter type often comprises aspects of crowd monitoring. First, we review a selection of articles concerned with computer-vision techniques for crowd analysis. Within these, ‘holistic approaches’ to crowd behaviour are the most relevant to the issue of emergency detection. This is the case because they have been the most concerned with the detection of anomalous behaviour in crowds, of which behaviour during emergencies can be understood as a subset. Second, we turn to non-vision based approaches for crowd monitoring, i.e. approaches that do not use cameras. We focus in particular on research being led by SOCIONICAL partners in which location-aware smartphones are being used to monitor crowd behaviour [76–79]. Third, and finally, we turn to another AmI technology developed by SOCIONICAL partners, known as the LifeBelt [25–27]. This research aims to optimise crowd behaviour during evacuations without necessarily requiring external monitoring.

The review then turns to traffic monitoring. Advanced driver assistance systems (ADAS) and intelligent transportation systems (ITS) are mentioned as utilisation areas. These systems support traffic safety and efficiency since they provide warning or information about the surrounding situation (e.g. congestion level, weather conditions) and as they increase comfort (e.g. ACC), safety or the ease (e.g. navigation) of driving action. Future developments are anticipated to be in many aspects of transportation, but especially in ICT systems (particularly in “cooperative” systems) in which great potential for improving traffic safety and efficiency is seen. In this section, the expected development in the level of interaction between infrastructure and drivers and its consequences are emphasized. Finally, challenges and key considerations for the implementation of new systems are mentioned. These include concrete factors such as costs or technical problems and more strategic factors such as data privacy and awareness of the effects and efficiency of the newly introduced systems.

The last section of this review concerns a problem faced by most researchers trying to optimise AmI systems for crowd evacuation, viz. the fact that it is impossible to test new technologies during real emergencies, and expensive and impractical to run large-scale ‘fake’ emergencies (on this issue see e.g. [59]). Computer simulation is often resorted to in order to test hypotheses on crowd behaviour and on how AmI might influence it. Simulating crowd behaviour is a vast topic and it cannot be surveyed exhaustively in this document. Instead, we narrow the focus to publications which are strongly related to research on evacuation.

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[1] In fact, this sometimes rendered the choice of publications to be included in this review problematic. In part, the fact that the review contains important amounts of research led by SOCIONICAL partners is an effect of their more frequent, explicit utilisation of the term ‘AmI’. In the absence of this term, we opted for a somewhat conservative view, including only those publications in which the connection to AmI is obvious.

2 AmI: Main Characteristics and Recent Suggestions

AmI is a recent field of research. The term ‘Ambient Intelligence’ came into use during the late 1990s [8,80]. The inaugural issue of a journal dedicated to the field was published in 2009 ([40], Aghajan H. & Augusto J.C. chief eds.) and a comprehensive handbook covering advancements in AmI was published the following year [55].

Some authors [64, p. 1] cite Norman [57] as having developed certain ideas in which it is rooted. More often, its early origins are situated in a well-cited paper by Mark Weiser [74], in which it was suggested that computing devices in the twenty-first century would become so ubiquitous that people would slowly stop noticing them. In other terms, Weiser predicted that various elements of hardware would reach a level of miniaturisation and interconnectivity so advanced that their users would engage with them quite naturally, without any strong, conscious realisation of doing so. This proposal is usually recognised as having provided the original impetus for the development of the fields of ubiquitous and pervasive computing. The field of AmI emerged in turn by calling for an understanding of the total integration of intelligent devices in the physical environment [1,2]. This can be interpreted as an evolution of Weiser’s initial vision: where he announced high levels of integration of computer networks in physical environments, AmI brings the crucial idea that these very networks can display intelligent characteristics. The term itself, ‘ambient intelligence’, was introduced by Emile Aarts ([80, p. 475], footnote 1). It came into use during the late 1990s and grew in popularity during the 2000s. [8, p. 2]

2.1 *Definition*

AmI is a field of research and technological development in which several prior fields of research converge: artificial intelligence and robotics, multi-agent systems (MAS), sensor networks, human-computer interaction (HCI), and pervasive computing (PeC) [8, p. 3]. As such, it is often recognised as inherently multidisciplinary [64]. Perhaps this explains the high number of definitions of AmI given throughout the literature. It is clear, however, that this plurality of definitions draws a coherent portrait of AmI, which has recently been concisely summed up by Aaarts and Ruyter [2, p. 5]: “In short, Ambient Intelligence refers to electronic systems that are sensitive and responsive to the presence of people.” Some noteworthy characteristics of AmI are given below, and a more detailed explanation of the concept features in the Introduction chapter “The SOCIONICAL FP7 Project”, to this volume.

- The AmI vision relies on the **miniaturisation of computing devices**. This is essential for their seamless integration into the environment, so that they may be ‘forgotten’ by users. The non-intrusiveness and omnipresence of computing devices is what is picked out by the term ‘ambience’ [2, p. 6]. Ultimately, the hardware layer becomes nearly invisible, leaving only the user- interface evident to the user [8, p. 1, 18].

- AmI devices form a **network that is embedded in the physical environment** and that is sensitive and responsive to people’s presence and behaviour [2, p. 5]. The number of devices that compose an AmI network is usually high, and they can be of various different types. [58, p. 1]
- The intelligent networks formed by AmI devices are often dubbed ‘**smart environments’** (see e.g. [8,20]). Such environments are meant to provide support for the people who live in them on a daily basis, with an emphasis on preserving ease of use. [2]
- The networks that compose smart environments are **context-aware**; they respond to new situations in a context-sensitive way. Put differently, they are sensitive and responsive to events in the physical world, which can be both complex and dynamic [4]. Such networks include vision and other sensor capacities to acquire information on the environment in which they are embedded.
- As well as a capacity to respond in function of context, ‘intelligence’ in an AmI context refers to **social awareness**: smart environments and AmI devices are capable of responsive interaction with the user [2, p. 8]. This feature has led to developing the concept of ‘socially aware computing’ [47]
- The interaction between technologies used in AmI and humans takes the form of a **feedback loop**: “the system reacts to human behavior while at the same time influencing it” [84, p. 103]

2.2 Exploring the Research Space

AmI is not a rigid or fixed discipline, but an evolving field of research. Some areas which are being explored include:

Synergetic prosperity: It has been suggested that the development of AmI has been mainly technologically motivated, rather than truly attending to user requirements. To counter this undesirable effect, Aarts and Grotenhuis have proposed the ‘synergetic prosperity’ model, which is more sensitive to users’ wants and well-being [1].

Human-centric computing: Similarly, researchers in AmI are now sensitive to the issue of human-centricity. The guidelines of Human-Centric Computing (HCC) potentially apply to all disciplines which involve computing. However, authors working in the field of AmI have called for investing the concept with new meaning, enabling the user to truly tailor an AmI network or Smart Environment to his personal requirements, so as to avoid any form of invasiveness [8, p. 7].

Pervasive Computing at Scale (PeCS) and the Internet of Things (IoT): The scale of the networks envisioned in AmI and the associated fields has grown immensely.

> This change of scale represents a new challenge for those working in these disciplines, especially insofar as it is crucial to maintain efficiency while scaling up networks to the size envisioned today [21]. The Internet of Things (IoT) [33] allows us to picture a world-wide network of billions of different objects all interconnected in one universal network.

In addition to these contributions, it should be noted that even when changes aren't delineated as drastically, AmI is being taken into many new directions: ambient control, tangible interfaces, end-user programming, sensory experiences, social presence, trustful persuasion, e-inclusion and ethics are just some examples of the many domains AmI researchers are exploring [2, p. 9ff].

2.3 Applications

Apart from crowd evacuation and traffic, which are discussed in the following sections, a number of applications of AmI are being developed.[2] Among these, some noteworthy examples are:

- *Health monitoring and assistance* [20, pp. 66–68]: Homes can become smart environments, providing health monitoring and assistance to those who need it. Two categories of population are targeted in particular: elderly people (e.g. [61]) and those with disabilities (e.g. [3]). Hospitals can also benefit from the introduction of AmI: "Applications of AmI in hospitals can vary from enhancing safety for patients and professionals to following the evolution of patients after surgical intervention" [19, p. 20].
- *Smart classrooms and smart offices*: Research on smart classrooms has shown various ways in which AmI can assist speakers and lecturers, and improve distance learning [29,62], while smart offices can accelerate decision making processes [67,81].
- *Entertainment and education*: Ndiaye et al. have developed "COHIBIT, an AmI edutainment installation that guides and motivates visitors, comments on their actions and provides additional background information while assembling a car from instrumented 3D puzzle pieces" [56].
- *Smart cities, AmI in urban environments*: As pointed out by Hollands [38, p. 303], the term 'smart city' has yet to be defined clearly. It has been noted, however, that "Cities are complex systems, composed of myriad biological and non-biological components that function and interact within multiple coincident spatio-temporal scales" [12, p. 1744] and that "'smart city' concepts are not just a vision but are currently being deployed in cities like Brisbane, Glasgow, Amsterdam and Helsinki" [12, p. 1760]. For a recent overview of AmI in urban environments, see Böhlen and Frei [15].

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[2] For a more comprehensive overview of the diversity of applications of AmI, see [8] and [69, pp. 73–74].

- *Emergency situations not related to evacuation*: There are forms of emergency response other than crowd evacuation, which can be improved through AmI. For example, tracking the location and health status of patients is a process that can be facilitated by the introduction of appropriate wireless sensor networks. Such networks could comprise "vital sign sensors, handheld computers, and location-tracking tags" and "have the potential for enormous impact on many aspects of disaster response and emergency care" [45, p. 22]. It is suggested that this may be particularly useful in situations where the health status of multiple victims needs to be rapidly assessed. In crowded environments, the improvement of evacuation is not the only issue that can benefit from AmI. Gerritsen [32] discusses aggression control, suggesting that equipping police officers and other individuals involved in aggression control with AmI devices capable of intelligently predicting high-risk zones will help reduce aggression and riots.

2.4 Measurement Approaches

When a complex system is designed, implemented or used, there are many situations, where an evaluation of the system is necessary. During the design phase, different high level models may be evaluated and compared to predict the behaviour of the system and to decide which model leads to the desired results. During the implementation of a system, many decisions have to be made about system parameters and local rules for the components, so an evaluation of different settings is necessary to achieve the desired results. During the run of an existing system, an evaluation can be used for an optimization of the system. For all these evaluations, the goal has to be specified in advance, such that the design, implementation and optimization can be done with respect to the specified goal. The challenges are:

- How can the goal be formalized in the mathematical model of the system?
- How can the mathematical model be evaluated with respect to the specified goal?
- How can the results of the evaluation be used to improve the design and implementation of a new system or for the optimization of an existing system?

In SOCIONICAL, different state of the art evaluation approaches have been explored.

2.5 Some Criticisms

Although the majority of publications are enthusiastic about the development of AmI, it is worth noting that some researchers have expressed doubts as to whether its goals are realistic [39]. Others have envisioned frightening 'dark scenarios' that AmI could bring about, in order to create a set of safeguards for its development [80].

3 AmI for Crowd Evacuation

Before discussing the way in which AmI can be used for the improvement of crowd evacuation, it is worth noting that the following operational understandings have been offered:

- **Crowd:** "a large number of people (and/or) things considered together" [26]
- **Evacuation:** the process whereby the crowd can be directed "towards safe exit(s) as fast and as calmly as possible" [26, p. 19].

These are quite clearly minimal definitions. For an extensive literature review on the meaning of crowds, see the *'Social Science Literature Review: Emergency, Queue and Crowd: Definitions and Cultural Comparisons'* prepared by the SOCIONICAL LSE team, 2012 (www.lse.ac.uk/complexity) [70].

Broadly speaking, two types of research on AmI technologies for the prevention of crowd disasters and the improvement of evacuation can be distinguished. First, AmI can be utilised to *collect* real-time information on crowd behaviour and to *detect* crowd emergencies, so that the prevention and response to such emergencies can be ensured through external means. This is typical of research which uses computer vision to monitor crowd behaviour, i.e. research in which computing is used to analyse data provided through cameras. There is an extensive literature on this topic, and a very brief overview is given in Sect. 3.1. In the second type of research, AmI technologies are used to *influence* crowd behaviour directly. Research with such an objective appears scarcer, although some SOCIONICAL partners have been exploring its potential. Section 3.2 reports on forms of crowd monitoring, which do not rely on cameras. Although these might be thought to fall under the first type, in which AmI is not used to influence crowd behaviour, there is an emergent trend (led by SOCIONICAL partners at DFKI, ETHZ and LSE) in which location-aware smartphones are used as the primary source of data on crowd behaviour. Since this allows for feedback and advice to be sent to individual devices (anonymously), the method potentially allows for direct improvement of evacuation processes [79]. Finally, Sect. 3.3 reviews research conducted by SOCIONICAL partners at Linz University on the LifeBelt, a wearable device capable of improving crowd evacuation by providing haptic feedback to its user, i.e. feedback through the sense of touch.

3.1 Approaches Based on Computer Vision

The bulk of the research in which sensor networks are used to monitor crowd behaviour and detect crowd-related emergencies is based on computer vision. Two literature reviews on this topic were published recently: Zhan et al. [82] and Silveira Jacques Junior et al. [69]. The former lists the multiple applications of computer vision for crowd analysis: public space design, virtual environments, visual surveillance, and intelligent environments. Of particular relevance to the present document is the application called 'crowd management'. Indeed, "crowd analysis can be used for developing crowd management strategies, especially for increasingly more frequent and popular events such as sport matches, large concerts, public demonstrations and so on, to avoid crowd related disasters and ensure public safety" [82, p. 345]. The second review makes a similar point: "[The behavioural analysis of crowded scenes] can be used for developing crowd management strategies, to avoid crowd related disasters and insure public safety" [69, p. 66].

Both documents survey various techniques and algorithms that have recently been developed in order to improve crowd tracking and analysis, pointing out that "The approach favored by psychology, sociology, civil engineer and computer graphic research is an approach based on human observation and analysis" [82, p. 345], whereas "computational methods such as those employed in computer graphics and vision methods focus on extracting quantitative features and detecting events in crowds, synthesizing the phenomenon with mathematical and statistical models" [82, p. 346].

[69, p. 68] opt for a tripartite division of the field of computer vision for crowd monitoring: 'People Counting' (which can be achieved through pixel-based, texture-level or object-level analysis), 'People Tracking', and 'Behaviour Understanding' (which can be studied using either object-level or holistic approaches). The topic of emergency detection appears most often in the sub-field of computer vision concerned with 'Behaviour understanding'. Indeed, crowd emergencies can be understood, to a certain extent, as cases of abnormal crowd behaviour.[3] Research on abnormal crowd behaviour detection using object-level approaches is described by e.g. Cheriyadat and Radke [18] and Ma et al. [48], however, it is an issue that is mentioned more frequently by researchers using holistic approaches. Some examples are given below,[4] however, we do not aim to provide a comprehensive overview of the algorithms used in computer vision to detect emergencies.

Boghossian and Velastin [13] note that "Closed Circuit Television (CCTV) systems are widely employed by police and other local authorities to monitor public events that involve crowd interactions in confined areas. The early detection, and so the prevention, of crowd-related emergencies are the main aims of CCTV operators." [13, p. 961]. They present a method whereby computer vision can assist CCTV operators in the early detection of crowd emergencies. The method is based principally on a motion-based approach to detect three critical indicators of crowd emergencies: circular flow paths, that "originate close to scene exits when large crowds attempt to evacuate the scene" [13, p. 962], diverging flows, an indication of local threats, and obstacles.

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[3] Although the study of abnormal crowd behaviour is not limited to emergencies, but rather, touches upon other subjects such as surveillance (see e.g. [42]).

[4] A number of the articles we mention below are reviewed in more detail in Silveira Jacques Junior et al. [69].

In a similar vein, Andrade et al. [6] present an automated, unsupervised solution for the detection of abnormal events in crowds. They note that "in scenarios where hundreds of cameras are monitored by a few operators, behavioural analysis of crowds is useful as a tool for video pre-screening" [6]. They propose a method based on an analysis of the optical flow of crowds involving unsupervised feature extraction and fitted hidden Markov Models (HMM) to extrapolate 'normal crowd behaviour' from video streams in which no abnormality occurs. This allows for the development of an algorithm capable of detecting abnormal situations in crowded contexts. The efficacy of the proposed technique is confirmed through computer simulation.

Ali and Shah [5] introduce a method using the principles of Lagrangian particle dynamics to detect instabilities in the flow of crowds, which functions by overlaying a grid of particles on video data to detect crowd flows and irregularities in these flows.

Mehran et al. [51] propose a method relying on the Social Force model [36] to detect crowd abnormalities that is specifically capable of detecting escape panic. The technique uses a combination of optical flows and a grid particle overlay in order to estimate the interaction forces between those particles. The technique is shown to be "effective in detection and localization of abnormal behaviors in the crowd" [51] and to outperform techniques based on pure optical flow analysis.

Kratz and Nishino [43] take on the challenge of producing an algorithm capable of computer vision based crowd analysis in extremely crowded situations. They point out that extremely crowded environments are difficult to analyse not only for computers, but also for human operators of video-surveillance systems, and therefore, a successful automated method would represent an important contribution. In the method they propose, which utilises "3D Gaussian distributions of spatio-temporal gradients" and Hidden Markov Models, the "key insight is to exploit the dense local motion patterns created by the excessive number of subjects and model their spatio-temporal relationships, representing the underlying intrinsic structure they form in the video" [43].

3.2 Non-vision Based Approaches

A considerable amount of research is being conducted on the utilisation of AmI in urban environments (see Sect. 2.3 above). In such environments, there is a trend in which non-vision based approaches are used to monitor crowds. This usually relies on aggregated data provided by location-aware devices such as mobile phones or GPS devices. Some examples follow.

The MIT SENSEable City Lab achieved real-time mapping of fluid components of Rome, i.e. of people and of traffic [17]. The collected data to achieve this came from devices such as mobile phones and GPS devices. Locational data was aggregated from a cell phone company, a bus company and a taxi company. Among the many applications of this technology, the authors cite its relevance to crowd monitoring. The study looked at people's behaviour during two very crowded events: "Viewing the World Cup final match between Italy and France on July 9, 2006, and celebrating the arrival in Rome of the winning Italian national team on July 10", and "Madonna's concert in Rome on August 6, 2006" [17, p. 252]. This real-time mapping of Rome was discussed further in a later paper, in which the authors point to some of the other potential applications of the technology: "The platform has potential applications in a variety of areas, including urban management, route planning, travel-time estimation, emergency detection, and general traffic monitoring" [16, p. 142]. Some technical details on the data collection for the Real Time Rome project as well as discussions of the directions the research might take are given in Reades et al. [63].

Even if they do not always explicitly mention emergencies and evacuation, researchers have investigated the possibility of using data provided by location-aware devices to map and monitor activity in urban environments. For example, such data collection processes have been used to understand the behaviour of spectators during sporting events [54], the way spaces are occupied during other important events [72], and a number of authors have discussed the application of this type of technology to traffic regulation [14,37,75].

SOCIONICAL partners Wirz et al. [76] have proposed utilising wearable acceleration sensors to detect group formations, arguing that "static infrastructure (e.g. cameras and communication system) may not work reliably or may not be deployed in the possibly unforeseen critical areas" and that "Current mobile phones provide sensors and local communication. Their prevalence may allow them to play a decisive role in the future to understand individual and collective behavior in real-time". Initial trials were run to demonstrate the potential of a proposed three-step procedure to infer crowd characteristics on the basis of the data delivered by wearable acceleration sensors. The validity of this method was further demonstrated in Wirz et al. [79], in which some further limitations of vision-based approaches are signalled: "Vision-based approaches face several limitations: Cameras cannot capture elements outside their fields of view or occluded by other obstacles and it is still difficult to fuse information from many cameras to obtain global situational awareness. Another drawback is the need for good lighting conditions. Furthermore, as many events happen during the night, the application of a vision based approach is limited" [79]. As an alternative, data collected from smartphones allowed the monitoring of several factors relevant to the prevention of crowd emergencies: crowd density, crowd velocity, crowd turbulence and crowd pressure. Trials using this technology were conducted during real-world gatherings: the Lord Mayor's Show in London, 2011 and the Notte Bianca festival in Malta, 2011. A promising feature of this research is its potential to go beyond information gathering and start influencing behaviour: "Police forces and event organizers are able to send push notifications directly to the users' mobile phone to inform them about critical crowd situations in certain areas and provide them with advice on how to avoid them e.g. by recommending alternative routes. Hereby, notifications can be targeted to people in a specific area so that only they receive the information, avoiding confusion among other, not affected users" [79]. Such targeted feedback might be crucial in speeding up evacuation processes, since people need to be distributed across different exits. A single message displayed on e.g. a screen or conveyed through loud-speakers could not achieve this goal as satisfactorily as a personalised message delivered through a smartphone (Wirz, personal communication).

3.3 LifeBelt: A Wearable Computing Device to Enhance Crowd Evacuation

There are cases in which AmI is used not primarily for monitoring purposes, but rather in order to influence people's behaviour in crowded situation in order to improve the evacuation process. One such project is the 'LifeBelt'. This device was initially developed by Fersha et al. without explicit mention of AmI or emergencies, but rather as a way of raising humans' attention to their spatial environment through haptic (mediated through the sense of touch) feedback, a channel that may solve the saturation problem affecting the visual and auditory senses [25]. The mechanism used is a vibro-tactile belt which is sensitive to local spatial information (as opposed to global, GPS-like information). The belt can indicate to its user both the position and proximity of obstacles through several vibrating segments which can operate at different levels of intensity.

The utility of the LifeBelt for crowd evacuation was demonstrated in Ferscha and Zia [26]. A 'next-step' model was created to simulate agents' decision processes regarding the direction in which to proceed during an emergency evacuation. This model was validated through three experiments involving 30 persons. While a number of these were instructed to evacuate a classroom as promptly as possible, the rest were told to act as motionless obstacles. Once validated, the model was used to parameterise a cellular automaton (CA) computer simulation system for large-scale evacuation (up to 2,000 individuals). This demonstrated that the feedback the LifeBelt provides on neighbouring obstacles can significantly accelerate the evacuation process. A later paper provided additional evidence for the effectiveness of the LifeBelt in evacuation processes [27]. More complex simulations were run, in which the evacuation of actual railway stations was tested.

4 AmI for Transportation

4.1 Advanced Driver Assistance Systems (ADAS) and Intelligent Transportation Systems (ITS)

A variety of ADAS [46,71] and ITS [52] have been employed to improve road safety and management.

ADAS range from safety systems that support drivers in safety-critical situations and stabilize the car (e.g. anti-lock brake system and electronic stability control), through comfort systems that reduce the workload of the driver (e.g. adaptive cruise control (ACC)), to information systems that carry out secondary tasks and give the driver important information (e.g. navigation system). Another categorization of ADAS is based on the level of intervention from information over recommendation and assistance to control [60]. Besides the intended safety and comfort issues, such systems are discussed because of their effects on traffic flow and environment [10].

ITS use sensors in the infrastructure to ascertain critical measures of road weather conditions and/or traffic flow. When a certain critical threshold is reached, the road regulations or warnings are altered via overhead signs (freeway traffic) or through traffic signals (urban traffic). This same information, especially concerning congestion, is communicated to the driver through radio announcements, a radio data channel for car radio or navigation device display and over the web to cell phones. Hence ITS could supply an input to ADAS. The combination of GPS tracking devices in navigation systems and phones has led to a number of systems where car positions are regularly transmitted using the mobile phone network to a central traffic information repository (e.g. Google Lat Long Blog, 2009[5]).

4.2 Future Developments

A study predicted the future developments in the area of information and communication technology (ICT) [85]. By asking more than 400 international experts from science, politics, and economics using the Delphi method (experts are asked in a multi-step approach, giving them information about the results of the previous step), future ICT innovations were prognosticated. Concerning the automotive area – a key industry in Europe – the results showed that current technology trends are intelligent driver assistance systems, light-weighted safety concepts, green engine technology, and mobile ICT systems. According to the experts, ICT-use in cars will rise by up to 50 % of value added (currently modern cars have a 20–30 % of ICT added value).

Cooperative systems, which are ICT systems able to exchange data with other systems, central servers, and the infrastructure, have a high potential in increasing traffic safety and efficiency. According to these experts, in the future the car will be a multi-functional and multi-modal node that will transmit hazard warnings and traffic related advice as well as personalised information and entertainment. But when will these future developments become real? When will 50 % of all new cars be able to communicate traffic and environment related content? Answering this question, 39 % of the experts predicted the period 2020–2024, 31 % the period 2025–2030, and 13 % the period 2015–2019. Although the experts did not doubt that these developments will take place, the time of their realisation was not clear.

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[5] Google Lat Long Blog: Arterial traffic available on Google Maps. http://google-latlong.blogspot.com/2009/08/arterial-traffic-available-on-google. html (2009).

Concerning ADAS, until now most of these technical systems were related to a single vehicle, e.g. automatic cruise control or lane departure warning. Currently and even more in the future, more and more cooperative ADAS are developed (e.g. hazard warning, automatic emergency call, intersection assistance) that are based on the communication between the vehicle and other vehicles (C2C) or vehicle and infrastructure (C2I; overall called C2X).

ITS will lead to vehicles that are not just information receivers but also information sensors and distributors. In this way, the driver will assist the infrastructure management, and hence other drivers, blurring the lines between ADAS and ITS, and between the drivers' levels of action they affect. These new feedback loops within both physical systems and driver levels of action have led to the term "cooperative systems" being frequently applied to new ITS technologies.

4.3 Challenges

According to experts [85], the most important barriers for implementation are the necessary investments into infrastructure (road side units), missing standards, high costs, issues of data privacy, and technical problems.

Concerning data privacy and ethical issues, innovative technical systems could feed the fear of a surveillance society that does not only monitor its citizens by CCTV cameras and credit or loyalty cards but also by mobile ICT systems that allow a comprehensive tracking of cars. Although this is done with the primary objective of giving important information related to current traffic, directions of appropriate parking, and warning of hazards – in short: enhancing traffic safety, efficiency, and eco friendliness – an abuse by criminals, companies, or the government is not impossible. Therefore, some ethical guidelines should be applied, if the tracking of persons/vehicles is a key requirement for future ICT systems Persons should be aware that they are being tracked, they must be able to withdraw at any time, data must be used for the agreed objectives and must be deleted as soon as possible [22].

Somewhat surprisingly, a study by the Deutsche Telekom in 2009 does not see the driver and the interaction between new systems and the driver as a major challenge for future research and development. As some systems carry out the driver's tasks (at least partially), the role of the driver begins to change from controlling to monitoring – the driver observes system performance and intervenes only if something is suboptimal. This could lead to new problems, e.g. reduced vigilance and situation awareness [9,24].

The next steps in technological development [11] – that will be driven by better sensor technology and faster data analysis – will lead to even more of the driving tasks being fulfilled partly or fully by assistance systems (e.g. lane keeping assistant, lane change assistance, stop & go ACC, collision warning, traffic sign detection, fatigue warning). The consequences for driving safety, (but also for the enjoyment of driving, [35]) must be analysed very carefully before such systems are brought to the market.

Clearly, the presence of ITS in traffic is serving to make the driver's decisions along the journey more dynamic and complex [23]. Much progress has been made in understanding system effects at the strategic level of action through the use of agent-based modelling to simulate complex evaluation decisions regarding routes [23], where the individual movements of vehicles are not of high concern. Leaving new systems aside, the global effects of systems already on the road are not fully understood. As an example, ACC ought to create platoons of drivers, theoretically reducing the likelihood of traffic flow breakdowns, yet there is debate about the actual in-vehicle uses and hence the global effects [50] of such a system. This is largely because the local interactions are relevant, but have not been closely examined and the results integrated into larger traffic models.

5 Validating Research Through Computer Simulation

One of the challenges that everyone involved in the deployment of AmI solutions for crowd evacuation faces is the difficulty of testing hypotheses, as regards both the unassisted behaviour of crowds and the influence of proposed technologies on this behaviour. Since it is difficult to test new devices during real emergencies, and to create large-scale, fake emergency situations (on the impossibility of trial studies, see e.g. [59]), most researchers turn to computer simulation to validate the solutions they propose. A sizeable part of the research on AmI and evacuation is devoted to the optimisation of such simulations; the present section reviews some discussions in this area.

It should be noted that, in comparison to research that refers to AmI specifically, the domain of computer-assisted crowd simulation is both older and much more extensive. [83] have produced a survey and summary of seven methodological approaches to the simulation of crowd evacuations: "cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theoretic models, and approaches based on experiments with animals" [83, p. 437]. This variety of methods might be due to the complex nature of crowd behaviour. New propositions on the best methods to simulate evacuations are made regularly. For example, one very recent contribution developed a way of modelling crowd behaviour during evacuation which takes into account emotions such as fear and panic [53]; another focussed on the evacuation of very large spaces [44].

One of the methodologies that have been used in order to efficiently model crowd behaviour in AmI environments is to collect data on agents' behaviour at a microscopic level, in targeted environments. The collected data is then used to validate a series of hypotheses that can be used to parameterise wider-scale simulations. This strategy was used by Zia et al., who coin the end-goal of this process "Evidence based Simulation" [84, p. 104]. A further development of this modelling strategy includes predictions from macroscopic theories of crowd behaviour, emerging from the domains of e.g. sociology or psychology. The authors have dubbed this combination of micro- and macroscopic data "mixed-level simulation" [84, p. 104]. Using this type of simulation enables them to test the efficiency of AmI technologies such as the LifeBelt through computer simulation.

Sharpanskykh and Zia [66] ran a number of computer simulations in which they parameterised different levels of trust displayed by humans towards AmI technologies, using the specific example of the LifeBelt. They developed a 'cognitive agent model' based on an elaborate understanding of the influence of emotional states on decision making processes. This model allowed for the levels of trust an agent has in a source of information to increase and decrease depending on previous experience with that source. On the basis of this model, they showed how the introduction of AmI technologies can lead to the formation of groups and the spontaneous emergence of leaders during evacuations.

Researchers have started exploring the "Potential of Social Modelling in Socio-Technical Systems" [28]. This is innovative, as most prior research focused primarily on the technological side of such systems, a notable exception being [34]. The development of a socio-technical model that accounts for human sociality requires the development of a 'Cognitive Agent Model' [28, p. 236]. In such a model, agents have several attributes: intention (trust, belief), emotions (fear, hope), and individualism (expressiveness, openness and contagion). By implementing this model in NetLogo to simulate the evacuation of a railway station, it was found that the percentage of agents using the optimal exit strategy by following those who are AmI equipped, increases with the proportion of AmI equipped agents (device penetration rate, dpr). This demonstrates that "it is important to model a socio-technical system at representative social (human) level" [28, p. 237].

SOCIONICAL partners at the AGH University of Science and Technology, Krakow, developed an approach using symmetry analysis for the modelling of crowd evacuation [68]. They ran computer simulations of the evacuation of a "long, high building constructed with identical fractions repeated in three perpendicular directions" [68], in which the process of evacuation was described as a transition from a chaotic state to an ordered state, and in which symmetry played a role. They came to the conclusion that "using [symmetry analysis] to construction [sic] of good models of evacuation is possible," and that, in comparison to Voronoi models, it produces longer evacuation times for small numbers of evacuating people, but similar evacuation times for higher numbers of evacuating people.

The 'social force model' (SFM) for pedestrian dynamics was initially introduced by Helbing and Molnár [36]. It is a way of modelling pedestrians' behaviour in more or less crowded situations which takes into account both physical factors such as the proximity of e.g. walls and obstacles, and social norms such as the tendency of individuals to maintain a certain distance between each other (sometimes understood in terms of the respect for personal space). The SFM presents advantages over other forms of modelling, such as 'cellular automata' and 'lattice gas' techniques, which statically allocate an area to each pedestrian and consider a pedestrian's behaviour to be totally determined by the local environment [30, B–77].

Because the SFM produces good simulations of pedestrians' behaviour, it has been used by several researchers as a model to predict crowd behaviour during the process of evacuation. For example, using this model, SOCIONICAL partners have shown that, in cases where a large number of people ($N = 150$) try to leave an area through a small exit, the probability that an individual can separate him- or herself from the evacuating crowd is very low. [31]. The same researchers were part of a larger team that ran simulations in which a large number of pedestrians evacuate a room through an exit, and the crowd pushes towards that exit. They found that "the evacuation process simulated here is not stationary", in other words, that "the SFM successfully describes the effect of cumulation of the physical forces between agents at the exit [. . .], the pressure at the exit increases with the crowd size. If this pressure exceeds some critical value, pedestrians at the exit are not able to move, even if they are close to the exit" [30].

A rather different type of simulation was designed by SOCIONICAL partners at AGH, who note that the issue of collaboration between robots is critical when robots are used for SAR (Search and Rescue) purposes, since collaboration can mean more efficient penetration of disaster zones. A simulation was run in which a number of robot ants were used to explore a labyrinth. Ants could communicate when they met. Results were formulated regarding the gain in penetration time (i.e. the time it took for the ants to acquire knowledge of the labyrinth) and individual ant knowledge of the labyrinth was a function of the number of ants. The authors point out that this research "can be useful in practical applications, as localization of victims in complex environment, perhaps after some disasters. In less developed technological applications, the ants can represent personal devices, which are capable to register the map of a local environment along the owner's trajectory and transmit it to another device" [49].

Another utilisation of computer simulation is presented by Andrade and Fisher [7]. Their research is geared towards computer vision approaches for the automatic detection of crowd emergencies. Training and testing such automated systems requires considerable amounts of video footage in which crowd-related emergencies occur. Yet such footage is not easily available. Using the Social Force Model [36], they create simulations of emergency situations and evacuations, which are then translated, using computer generated imagery, into virtual footage which can be used to train and test computer vision algorithms for the detection of crowd-related emergencies.

Computer simulation of crowd behaviour is not necessarily geared exclusively towards the detection of crowd emergencies or towards testing new hypotheses on the possible influence of a new technology on evacuation processes. Sagun et al. [65] argue that it can be used to enhance building guidance and to design safer buildings: "Predictive crowd simulations can support the building design process by exploring the designs under certain conditions that occur in different buildings and circumstances by using scenario-based studies" [65, p. 1008].

Finally, SOCIONICAL partners at AGH have prepared a real–time simulation of a whole stadium area using a modified Social Distances Model of Pedestrian Dynamics. The application was presented under the title "Proxemics in Discrete Simulation of Evacuation" during the10th International Conference on Cellular Automata in Research and Industry – Crowds and Cellular Automata [73]. Figures 1 and 2 below, show the simulation of an evacuation of the Allianz Arena stadium, Munich, using the Social Distances Model.

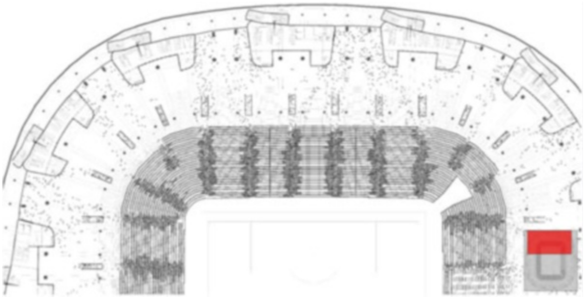

Fig. 1 Simulation of Munich Allianz Arena using Social Distances Model

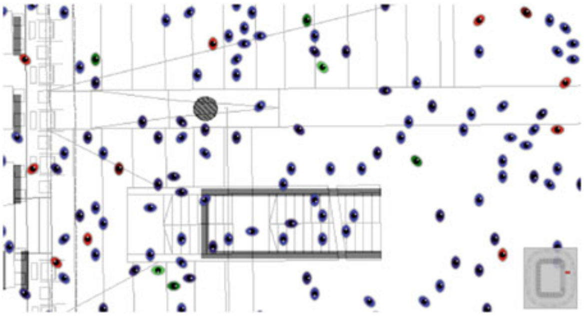

Fig. 2 Allianz Arena evacuation – different colours of agents represent different maximal velocities

The Social Distances Model was introduced by Was, Gudowski and Matuszyk [41]. It has been modified to enable the simulation of crowd behaviour in large facilities. The simulation is able to represent the **behaviour of 70,000 agents in real time**. The agents have abilities at strategic, tactical and operational levels.

Spatial relations between agents are represented using the Social Distances representation (Fig. 3). The relations are applicable in normal situations, when classical territoriality among pedestrians is observed.

In evacuation scenarios the crucial parameter is crowd density. Exemplary configurations in an agent neighbourhood for different values of probability are presented in Fig. 4, below:

6 Conclusions

This document reviewed recent research on two applications of AmI technologies: improving crowd evacuation during emergencies and improving traffic management. On the basis of the articles that were surveyed, we come to the following conclusions:

First, AmI is a relatively new field of research of technological and socio-technical development. It is multidisciplinary by design, bringing together a number of prior areas of research. Hence, the field is not rigid, and future research in AmI

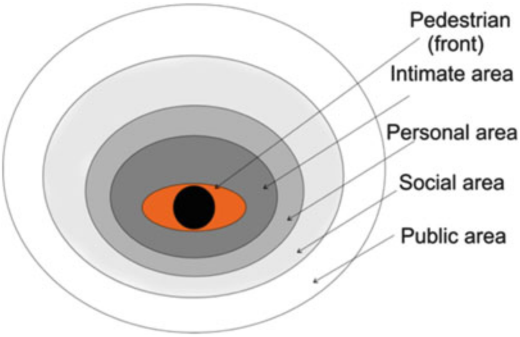

Fig. 3 Social areas representations using Social Distances Model – asymmetric social areas around a pedestrian

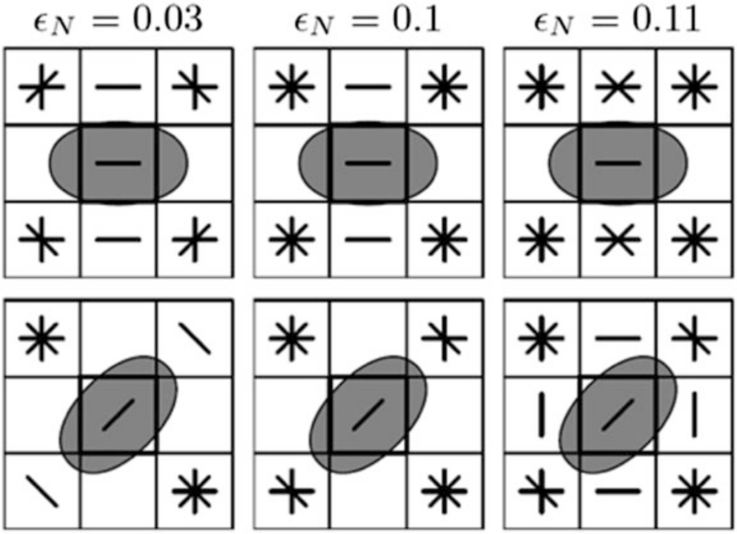

Fig. 4 Allowed configuration in an agent neighbourhood for different values of compressibility parameter

might evolve in several directions. New suggestions have been made recently concerning the scale of deployed AmI networks, the flexibility of their utilisation, and the way in which user-interaction is conceived.

Second, explicit mentions of emergency situations and evacuation in the AmI literature are more recent, but it appears that this area of research is burgeoning quite rapidly, in particular among a number of SOCIONICAL partners that are exploring its various aspects.

Third, research on the utilisation of AmI in emergency situations and for purposes of evacuation can be divided into two types. The first type comprises research that utilises AmI primarily for purposes of monitoring and early detection of crowd-related emergencies, the second encompasses research in which AmI is seen as a way of influencing and modifying the behaviour of individuals in crowds in the hope of improving the evacuation process. There is some overlap between these types.

Three AmI technologies for the improvement of crowd evacuation were discussed in this review. The first, predates the term ‘AmI’ but it can be included in the field since it is based on sensor networks and uses computer vision for crowd analysis. When approaches are concerned with the detection of anomalous crowd behaviour, they become relevant to the topic of emergency detection, since to a certain extent, crowd-related emergencies can be understood as a subset of anomalous crowd behaviour. The second technology uses location aware devices such as mobile phones and GPS devices to monitor crowds and detect emergencies. In the case where data is collected through smartphones, this potentially enables the modification of crowd behaviour through personalised, push-message feedback. The third technology is being developed by SOCIONICAL partners at Linz University; it uses a wearable computing device, namely a vibro-tactile belt, to provide guidance to its user in evacuation cases where other sensory channels might be impaired or overloaded.

As far as traffic is concerned, AmI technologies are used to assist traffic safety and efficiency as well as to improve environmental and comfort aspects of transport. Existing systems (ADAS and ITS) help drivers by providing information (e.g. weather condition or congestion) and assistance (e.g. navigation) or by controlling the vehicle (e.g. ACC). It is expected that traffic safety and efficiency will be improved by the developments in information and communication technologies (ICT). Increased communication and data exchange are expected to change the roles of vehicles and drivers in transportation systems. Vehicles will shift from receiver to sensor/distributor, while drivers will partly shift from controlling the driving to monitoring. There are also challenges, regarding AmI systems, which should be considered. Aside from obvious challenges such as costs, standards and technical complexities, data privacy is an important issue, which needs serious consideration. It is also highly important to understand global and local effects of new systems before widespread application in order to achieve the desired outcomes of a new system.

Furthermore, there is a problem, which most researchers involved in the development of AmI technologies to improve evacuation and prevent crowd-related disasters, face. This is the obvious impossibility of testing newly proposed technologies during real-world emergencies, and the impracticality of creating wide-scale ‘fake’ evacuations. Most researchers turn to computer simulation to validate their hypotheses. The literature on computer-assisted crowd simulation is extensive, and only selected contributions most relevant to AmI technology and crowd management were discussed here. One popular model is the Social Force Model [36], which is a relatively simple yet highly accurate way of modelling crowd behaviour, which takes into account both physical constraints and social norms in pedestrian behaviour. Using this model, several new findings on crowd dynamics were made.

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