UNDERSTANDING HOW BIG DATA AND CROWD MOVEMENTS WILL SHAPE THE CITIES OF TOMORROW

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1. INTRODUCTION

1.1 A brief history of crowd modelling. From direct observations to simulation

In 1895, the French social psychologist Gustave Le Bon wrote "*The age we are about to enter, will truly be the Era of crowds"* in his book *"The Crowd: A Study of the Popular Mind"* (*Psychologie des Foules* in French). If we take the 8am train to go to work, if we walk through a popular street on a Saturday, or if we go to a big event, we can see Le Bon's words as a prophecy that describes the world in which we live.

Pedestrian planning and crowd modelling have became more important in the last decades, mainly due to the increase in the number of big events that are organised and the accidents that sometimes happen during these events (Evers, 2011). Nowadays, architects, engineers, transport planners and event organisers make use of advanced software and mathematical models to predict the way in which pedestrians will move through train stations, streets, buildings, or stadia in order to create safe and efficient environments. In parallel to them, researchers and scientists are developing new algorithms and tools to improve the accuracy of the predictions. However, the first studies in this field were just based on direct observations, and they set the starting point for further research.

According to Baer (1974), a good part of the research done in this area can be classified as behavioural studies related to sociopsychology rather than the direct influence of the constructed environment on pedestrian flows. Goffman (1963), for example, described a subconscious process called scanning used to avoid small obstructions in the flooring, through which a pedestrian checks other pedestrians that are in an ellipse around him, whilst people that are not in that area are ignored. Wolff (1973) wrote that a high degree of cooperation between pedestrians is a crucial attribute of pedestrian behaviour, and he studied the cooperation needed in the completion of the walking tasks. Dabbs and Stokes (1975) and Sobel and Lillith (1975) focused their research on how pedestrians grant space to others depending on different attributes: gender, beauty, or group formation. Although these authors collected a big amount of observations, neither developed an explanatory model to predict how pedestrians will move in a certain scenario.

Baer mentions another category of research formed by technical studies in which the authors developed norms and safety standards. One of the best-known researchers in this field is Fruin (1970s), who studied the relationship between different parameters of pedestrian movements (speed, density, etc.) and acceptability, and developed the concept of Level of Service for pedestrians that is still used nowadays in the designing of safe spaces. Predtetschenski and Milinski (1971) also studied the dynamic behaviour of pedestrians in constructed environments, obtaining critical parameters to be used in design. They found, for example, that the flow speed is related to the density, the type of route, and a psychological factor. However, these authors mainly focused on unidirectional pedestrian flows and on static behaviour and their analyses were based on regression relations that fail to predict pedestrian flows in complex situations such as opposing flows, multiple route choices with varying degree of obstacles, buildings with complex layouts, challenging evacuation situations, and so on. Furthermore, these studies did not take into account the self-organisation effects that occur in real pedestrian crowds, such as one entity squeezing him or her to give way to the other on a narrow aisle, or entities changing their routeing decisions on spur of the moment based on their observation of forward congestion or perceived assessment of the quality of the journey.

Since these first empirical studies, based on black and white photographs and Super 8 films, the era of simulation models began. Henderson (1974) proposed a model to reproduce spatio-temporal patterns of motion, and surmised that pedestrians behave similar to gases or fluids. In his fluid-dynamic approach, he used Navier-Stokes equations with significant success. However, these types of models did not allow modelling of individual pedestrian motion which is not very practical as they do not take into account local co-ordination problems. Also, although fluid-dynamic theories work quite well in normal situations (medium densities), granular aspects prevail at extreme densities including panic situations and evacuation *(Helbing and Johanson, 2010).* Therefore, research in this field mainly focused on agent-based models. As an example, Reynolds (1987) developed the *boids* model (*boids* refers to bird-like objects) by studying how a very simple behaviour of one boid of a crowd (microscopic level) can result in a complex macroscopic pattern that can be analysed mathematically using three rules: 1) boids try to move towards the centre of mass of neighboring boids, 2) boids try to keep a small distance from other objects or boids, and 3) boids try to match velocity with near boids. This means that the movement of boids are highly dependent on each other (dynamic model).

Although human behaviour can be perceived as chaotic, irregular, and non-predictable (Weidlich, 1983), Helbing (1992 and 1995) thought that pedestrians are used to the situations they normally experience, so the reactions they choose are automatic and determined by their previous experience of which alternative will be the best. On this basis, Helbing developed the so-called social force model by creating equations of motion for pedestrians taking into account that the preferred velocity of a pedestrian is described by a vectorial quantity (social force) that describes his motivation to act (acceleration or deceleration) caused by the perceived information that he obtains from the environment (other pedestrians, obstacles, etc.). Helbing summarised it saying that *"a pedestrian acts as if he or she would be subject to external forces".*

1.2 Understanding the limitations of historic research

In recent years, the amount of research done in this field has significantly increased mainly due to the rising importance that pedestrian modelling has for society. Taking into account that by 2050 over 70% of the world population is predicted to live in cities (Weidmann, 2012), the urban infrastructure and the transport systems will have to be ready not only to accommodate the increased demand, but also to minimise the risks during emergency situations. Furthermore, the organisation and planning of major events such as the Olympics or the FIFA World Cup is getting more attraction from the media due to the economic and political fallout that a badly organised event may cause for the country. Nowadays, crowd modellers have to deal with more difficult scenarios such as shopping centres, hospitals, schools or streets, where people interact with the space and with themselves in a very complex way. However, the more complex our scenarios and models are, the more we know about the lack of knowledge we have in this field.

Today, data collection is one of the limitations that crowd specialists have to deal with. Experiments and direct observations have been the main source of data to create empirical models and to obtain information (inputs) to be used in the models. Until recently these have historically been largely sufficient for the level of accuracy required and achievable by the hardware and software available, as well as taking into account the level of importance and application allocated to their outputs.

In recent years, however, crowd modelling has been rising in prominence due to a number of factors coming into alignment: firstly, key decision makers are increasingly accountable for poor choices in the design and planning stages and so are keen to reduce risk as much as possible. With many more stakeholders now educated in the use of, as well as the benefits of, pedestrian modelling techniques and outputs, they are demanding greater use of this tool in far more varied scenarios; secondly, pedestrian modelling software has developed in complexity, permitting greater functionality to better represent real-life situations; thirdly, hardware developments are allowing much faster processing rates so that bigger and more complex environments than ever before can be modelled. But as the range and complexity of models increases and the level of questions being asked becomes more detailed, this is beginning to show gaps in the industry’s knowledge that need to be plugged as quickly as possible.

Examples of what is missing or not understood well enough can be categorised broadly into three categories: first, historic data – much of the research on which our understanding and industry guidance is based is several decades old. In the time that passed in between a great many changes have happened within society, including ageing of the population, changes to working practices with more working from home and greater sharing of parenting roles between genders, a general decline in fitness levels coupled with increasing physical size of people, and so on. In short, the population passing through a busy train station or attending a football match is likely to be very different in characteristics from that visiting the same station and stadium 40-50 years ago. This raises the fundamental question “are the standards and guidance the crowd modelling industry uses still fit for purpose?” It may be that some standards are still robust and just as accurate as they were when established many years ago, but revisiting some of this research to confirm it with new observations would add credibility and reassurance to the industry, whilst at the same time providing much-needed updates in some instances or perhaps adding additional standards that reflect today’s pedestrian movements and needs.

A second vital category is simply ‘missing data’. As crowd modelling is applied to more and more areas, it is not surprising that increasing numbers of scenarios have simply not been analysed in reality either at all or in sufficient quantity and quality to be of use when determining key input values. This may be because nobody previously considered it to be of sufficient interest to collate, or because the technology for doing so was inaccurate or did not even exist at all, or the parts of those databases are too sensitive for normal methods of collection. But as the level of accuracy to which pedestrian modelling is applied increases, so too must the accuracy of inputs used. At a higher level this used to mean not simply applying a standard rate of movement to all situations (i.e. one flow rate should not be used for transport, sport, festivals etc), but now it is expected that different inputs are applied for different *types* of football match, different *types* of festival and so on. Detailed understanding and responsible forecasting can only be achieved with more and better collation of data for as many types of scenario, for as many occurrences as possible so that statistical trends and observations can be determined with confidence.

Closely related to this is a third category: ‘lack of accurate data’. As mentioned before, in the past (and still today), data capture has been hampered by lack of technology in itself or of affordable methods of data collation and analysis. Field observations are often impractical in complex scenarios where a large amount of information about route choice, flows, speed, spatial distribution patterns and complex behaviours is required, and particularly so for larger studies that go beyond a single building or open space. Compared with traffic movements, pedestrian movements are significantly more complex and difficult to track due to the much more porous nature of the ‘network’ within which pedestrians move: whereas vehicles will for the most part arrive and exit a study area by roads and major origin/destination points such as office or retail car parks and with few intermediate on-street or residential parking in between, pedestrians may come and go from a study area via almost any doorway, side street or cut-through, may double-back, stop and wait, change modes to bus, train, taxi, cycle or other, and then resume walking again. They may also travel underground for large parts within major cities, cross at non-designated crossing points, be affected significantly by different weather patterns, and may be influenced much more by factors such as travel distance, personal security and safety – including fear of falling for older pedestrians (*De Jong, M, 2012*) – than other mode choices. It is little wonder that truly accurate pedestrian movement data for larger scale studies has been virtually impossible and certainly impractical for many to consider pursuing until recently.

Aside from lack of data, the planning process itself has hampered understanding of larger scale pedestrian movements. Traditionally planning for pedestrian environments has been very much a fragmented approach, with almost everything assessed in isolation: rail stations, multi-story office blocks, pavements and so on. This is as much down to the planning process as anything else – each development is assessed by local authorities or other stakeholders to quantify the likely impact on the footprint of the development and the immediate surrounding area. Developers are not surprisingly usually unwilling to spend additional money on wider areas unless there is a direct benefit to themselves via the attractiveness and hence value of the proposed development. Thus improvements might be made to bus or rail facilities serving the development since these are high in the list of services potential users of a development would seek, but it is unlikely that an improvement to pavement width, quality of pavement surface, crossing provision and so on would be investigated by many people prior to making a decision to travel to the development: there is an innate assumption that these facilities are to a high enough standard already.

But with some city centres experiencing more and more high-density development there is now a real risk that what is taken for granted might not be sufficiently fit for purpose for much longer: pavement capacity may be exceeded as buildings with space for thousands of workers, residents and retail users are built in areas currently providing a fraction of that in terms of pedestrian demand. An example is the City of London where it is anticipated that many such high-rise developments will take place over the next 30 years, meaning that tens of thousands or even hundreds of thousands more pedestrians may need to walk to and from places of work during the peak commuting periods, and all within a limited area of the city. This will put pressure on the already busy pavements, and may require changes to road usage such as lane closures and pedestrianisation of specific lanes or whole sections of road to cope with this increase in demand. Alternatively innovative developments such as elevated ‘sky walks’ may be proposed in some areas, or further development of particular areas may need to be curbed, which can be difficult when commercial pressures come to bear.

But whatever the mitigation measure chosen, wider-scale understanding of existing and predicted pedestrian movements will be needed so that an integrated approach to planning of transportation can be achieved successfully and efficiently.

1.3 Current research and limitations

Due to the lack of necessary information to realistically model crowds, different techniques used to improve the automatic detection of, and tracking detection of, pedestrians using videos have been developed in recent years that are valid for scenarios with both low and high crowd densities *(Dehghan et al, 2012; Duives et al, 2012)*. Researchers are making use of these technologies to improve the accuracy of the models (validation and calibration) as well as to derive new theories. For example, Federici et al (2012) used video records and showed that groups are a basic constituent of crowds and that the greater the size of the group, the lower the walking speed is. Wagoum et al (2012) found that the shortest path is not always the strategy used by pedestrians to leave a venue and commented on the implications that this might have for evacuation modelling, and Burghardt et al (2012) made a critical review of the existing diagrams for stairs (Fruin and Weidmann among others) and used video cameras to create a revised fundamental diagram.

Although these new techniques have allowed us to partially bridge the data gap, they fail to represent certain aspects of human behaviour *(Almejmaj and Meacham, 2012),* as they normally focus on *how* pedestrians move instead of *why* pedestrians move. According to Brudermann (2012), an integration of mass phsychological insights into architecture, urban planning and crowd modelling is crucial to understand how and why people move. However, although these different fields are the foundations of crowd dynamics, they usually follow parallel paths which are difficult to join together.

Different researchers on mass psychology *(Schultz, 2012; Zinke, 2012)* have criticised that microscopic models (force model, its improvements or other specific models) do not take into account psychophysical concepts, intra-group coordination effects, or human behaviour aspects. Others *(Moussaid, 2012)* have investigated about the use of heuristic models to take into account the internal cognitive processes that lead to a certain movement made by a pedestrian. All these authors stress the importance of the integration of individual personality patterns into the current models. However, the difficulty in collecting such data, and the ethical challenges that this involves makes it harder to overcome, and data collection has became for crowd specialists the major hindrance from progressing.

Either due to privacy, ethic or technical reasons, or simply because society has just started to understand the importance of crowd movements, the lack of large-scale real world data on pedestrian movements and behaviours acts as a brake that impedes how new models – such as route choices models – are developed *(Bauer and Gantner, 2012)*. According to these authors, a large amount of data could be obtained using different technologies. For example, they indicate that 10% of people could be tracked nowadays using Bluetooth scanners. Other authors *(Danalet et al, 2012)* have proposed a probabilistic method to obtain pedestrian destination data (the location and the time spent at it) using WiFi traces. However, nowadays, the possible bias that could be introduced in the data (just people using smart phones would be tracked), and the limited information that can be obtained through these techniques (no information about gender, behaviour, or use of space) increase the need for further research on this field and make it very difficult to apply it in current projects. Nevertheless, researches agree that a new Era for crowd specialists is about to begin: the Big Data Era.

2. BIG DATA

There is a lot of discussion in the media about ‘Big Data’, but what actually is it? For some it may refer to incidental data that is collated as a by-product of collating certain specifically targeted data. Retail and banking organisations may search for buying patterns amongst existing or potential consumers by tracking specified items and looking for trends associated with income, age, earnings, weather patterns or even historic buying patterns of other goods. But whilst looking for meaningful targeted patterns within a large data set (which could be billions of grocery items bought by millions of people over a large period of time), there may be many other patterns which are overlooked that could prove beneficial to an organisation if only they had thought to look for them.

Another definition, and the one that will be used within this paper, is that Big Data is generally speaking an all-encompassing term for any collection of data sets so large and complex that it becomes difficult to process using on-hand data management tools or traditional data processing applications. The data collated is so large that it may require hundreds or even thousands of servers working in parallel to process such vast amounts of data. Why is this occurring? Because now there are so many ways to record events electronically for everyday activities, and where there’s data there’s usually money to be made by sales and marketing activities, which has led more and more organisations to record more activities and to then try to analyse them.

One of the spin-offs for transport planners is that some of this data can be investigated for use in tracking movements of vehicles and people on a scale never before imagined. In particular the use of Global Positioning Systems (GPS) has become more and more widespread in standard every day devices such as mobile phones, watches, laptops and notepad devices, and is even being pioneered for use in clothing which can be particularly beneficial for elderly/infirm people who may require emergency medical assistance without being able to raise an alarm themselves (*Charlon et al, 2013*). The potential to use the information generated by these devices across large populations and over large geographic areas has finally offered the real prospect of pedestrian modellers being able to understand city-wide movements at a level of detail and accuracy never before imaginable.

But here we must introduce a note of caution: with Big Data comes the potential for Big Mistakes! As exciting as the prospect may be of using this data to create origin-destination matrices or to predict profiles of demand, it must be remembered that it is still just data and needs to be treated like any other traditional data gathered by surveys: i.e. it is vitally important to understand *what* we have exactly before we apply it. Indeed, this question is perhaps more important for Big Data than traditional data sources from pre-planned surveys, since Big Data sources are likely to have come from a ‘dump’ of data that is neither pre-planned nor screened. Ensuring we precisely understand the data we have been given, as well as its limitations, is vital to avoid making errors on a truly ‘big’ scale.

Initial work undertaken in the UK has been carried out on telecoms data by a variety of consultants and authorities to ascertain what exactly this data can tell us with regard to people movement regardless of mode. Initial findings suggest that there may be some valuable data that can be of use for vehicle-based studies, although at present there can be problems defining which vehicle type is being used by people. Also it can be difficult to determine from data alone whether large journey times over small areas are as a result of traffic congestion, vehicles waiting / parking outside convenience stores / ATMs, or whether people switch mode from car to walk to bus and so on. Certainly one view to come from this data so far is that it is very difficult to use it in any accuracy for pedestrian movements. This is mainly due to the lack of sufficient granularity of telecom cells, and also that cells can change shape and size as phones seek the best signal strength from nearby masts, and may change at almost any moment depending on the particular strength of signals from individual masts.

Alternative suggestions to mobile phone data might include tracking credit and debit card payments by point of sale location. However, outputs from this would be of limited use for tracking pedestrian movements other than to establish general daily / weekly commuting or shopping patterns when aggregated over a period of time. Certainly there would be very limited or no inputs regarding route choice and journey speed.

So it appears that for the moment Big Data will not be able to directly inform detailed analysis and understanding of pedestrian movements. It would require development of technology to allow tracking of mobile phone devices in much more detail and accuracy, certainly to within a radius of 50m or less.

However, it is not all bad news. There is technology already in existence that allows detailed pedestrian movements to be recorded and understood. Software to allow tracking of individuals using sensors is something that can be achieved (*Nikolic et al, 2013*), and also using a methodology that preserves anonymity of individuals. Essentially the software compares the silhouette of a shape (a person) as they move out of the field of view of one camera and into an adjacent camera's field of view, rather than facial recognition. By comparing the two shapes and time delay between leaving one and appearing in another, the software can accurately deduce where the same individual moves through an area between multiple cameras provided there is continuous visual coverage, or at most minimal gaps between cameras. However, due to the limitations of the field of view that can be accurately covered by the cameras and associated software, and the cost of setting up and calibrating the equipment, this has not yet been explored beyond a limited physical area such as a large rail station.

Nevertheless, the potential remains for this technology to be expanded in scale as required, provided the funding can be secure to set it up, since the cost of collating data once it is active is minimal, and a year's worth of data could automatically be collated for not much more than the cost of a few weeks' traditional data collection. The benefits of this would enable accurate Origin-Destination matrices to be developed, seasonal fluctuations to be understood, and even differences associated with changing weather could be determined, as well as behavioural traits such as dwell times, walking speeds, route choices and so on. Collecting data in this manner within a study area is not perhaps 'Big Data' as we have defined earlier, but if the technology were to be applied to a network of existing cameras (e.g. CCTV), then there is the potential for citywide movements to be captured and understood much more clearly than ever before, though it is likely some adaptations to the software would be required to cope with different camera outputs, as well as processing of such enormous amounts of data.

3. CONCLUSIONS

The use of crowd flow modelling is increasing in scale and complexity, with more applications than ever before as planners, designers and stakeholders understand and appreciate more the value of outputs from pedestrian modelling. With understanding and improvements to software come ever greater demands as more detailed questions are being asked.

The existing underlying data and research supporting the industry is no longer adequate to be used as inputs for all scenarios, and we believe requires a concerted and co-ordinated effort between those responsible for standards and guidance, academia and professional organisations which rely on this data to inform their design or operational assessments.

New technologies and data capture are emerging that will improve wider understanding of transport movements across medium to large (strategic) areas, but at present none of the 'Big Data' formats appear to be directly applicable to the micro-simulation scale. If public planning authorities for large cities wish to have access to automatically generated data of pedestrian movements on a large scale there will need to be further technological developments allowing refinement of the scale of origin-destination movements to be achieved, most likely with mobile phone tracking since these are the most widely carried trackable devices currently in circulation. This will become more and more critical to planning of cityscapes as city populations grow ever higher, proposed developments get bigger and physical walking space becomes limited.

Understanding and predicting pedestrian volumes, movements and behaviours for cities, 'mega events' and emergency planning will continue to increase in prominence, and it is vital that the industry recognises the opportunities that are arising through technological developments and engage with those involved to ensure that we can shape developments in line with what is needed. If a market can be seen by those generating the data and the financial benefits are sufficient, then data will become available in due course, but it is the responsibility of professionals in all areas to engage with technology providers now to ensure that this market can be envisaged and opportunities to influence technology developments are not missed.

We are at an exciting time in our industry, with potential to grow our involvement into all areas of pedestrian movement planning, but must start exploring beyond the data and methodologies that we have used to date. We have a responsibility to challenge, investigate and improve upon all areas of data capture and understanding of pedestrian behaviour, which can potentially take the science of pedestrian modelling to new heights of application and robustness.

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