Data-driven Interactive Crowd Management Systems for Metaverse Scenarios

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***Abstract*—Understanding human behavior in urban settings has never been more accessible thanks to the growing accessibility of enormous volumes of data produced by people, cars, and other connected objects. We are entering a new era of innovation and creativity with the Metaverse. It will integrate comprehensive technologies such as 3D imaging, eXtended reality (XR), and advanced sensing into next-generation Internet services. Moreover, recent advances in disruptive technology, such as Artificial Intelligence (AI), and Machine Learning (ML), adding to the increasing decentralization of the Internet due to the possibility to deploy complex analytics across Edge-Cloud, are driving the further development of the Metaverse, as a 3D network of experiences and services. It allows users a sense of synchronous and persistent presence, with continuity of data, which highlights Crowd Management (CM) techniques to manage and control data-driven communications. CM techniques are vital in channelizing the data to help design mobile networks, control emergencies, and plan infrastructures. In this research, we will provide an overview of CM, its properties, and its functional breakdown following the integration of AI into CM. We will introduce the concept of Metaverse Crowd Management (MCM) and examine the various scenarios and associated challenges and opportunities.**

***Index Terms*—Crowd Management; Metaverse Cities Ecosystem; Metaverse Crowd Management; Artificial Intelligence; Data-driven CM Framework.**

I. Introduction

Science and technology advance the boundaries of knowledge and have profound, lasting effects on society, illuminating how social reality changes over time. The Metaverse [1], a collection of fictional depictions of technologically advanced future worlds, is progressively influencing the socio-technical visions of data-driven smart cities, which are the results of profound changes in prevailing structures, processes, practices, and cultures. The links between scientific knowledge, technical systems, values, and ethics from a wide range of perspectives are at the heart of the systematic examination of science and technology. Metaverse has opened a new era of innovation and creativity. The word "meta" implies transcending, and the suffix "verse" are combined to form the term "Metaverse." It describes a digitally created environment that is linked to the real world.

People worldwide choose to live in cities due to the rapid advancement of technology. The trend of urbanization has spread to practically every nation in the world, and it is anticipated that the population of cities will continue to rise. According to a United Nations study [2], by the year 2050, more than 68% of the world's population will reside in cities. In contrast, this ratio was only 30% in 1950 and is today about 55%. Urbanization also reflects the advancing usage of technology in everyday chores.

The amalgamation of urbanization, Metaverse, and advancing technologies have raised the levels of user needs and requirements. The transition towards smart cities has also raised concerns regarding managing enormous populations and generated data. This trend also leads to the creation of 'Crowds,' i.e., accumulated groups of people. These accumulated crowds have raised high concerns among the authorities to manage, regulate and control services and amenities [3]. Better city planning and restructuring are required as a result of this rapid development in urbanization. The emergence of large groups of people, their forecasting, effective management, and control are some of the most significant difficulties that have emerged. For instance, rush hours at the start and conclusion of each workday and the large number of people attending various events present a significant problem for traffic management and mobile communication.

Science fiction components offer us a sneak peek into the upcoming new realities and urban issues. What good are the enormous sums of money we are currently investing in making our cities more livable, egalitarian, and sustainable if future residents will only have a virtual experience of the city? Numerous metropolitan attractions like theatres [4], dining establishments, museums, and historical sites will experience a decline in the number of visitors coming through their doors. Several museums [5] are already accessible virtually. Metaverse is also seen as the fourth-generation computing platform [6] that will execute a software on a virtual environment and will be based on advancing technologies like Artificial Intelligence (AI), Machine Learning (ML), Virtual Reality (VR), etc. Thus, the necessity for new techniques to foresee and manage crowd forms arises from the global population's concentration in certain regions.

The remaining of the paper is organized as follows. Section II will briefly discuss an overview of Crowd Management (CM), its properties, and its functional breakdown. Section III introduces the concept of Metaverse CM. Section IV presents the impact of AI on CM. Section V discusses the opportunities and challenges. Finally, in Section V, the main conclusions of this work are drawn.

II. Crowd and Crowd Management

Crowds are an inseparable part of modern urban society – random gathering of people due to their similar daily routines, occurring during cultural events as exhibitions, concerts, different sport events, protests, intense traffic during weekends. A definition according to [7] is a collective situation in which individuals come together, with a shared purpose, around a specific location, during a time interval. Another definition can be found in [8], where crowd is described as collection of people, classified into different types depending on people's activities or behaviour. According to [9] "when many people gathered with a shared purpose or shared emotions, this is called a crowd".

Crowd types can also vary depending on each authors points of view. In sociology, a crowd can be casual, conventional, expressive and acting; in security area – casual, sighting, agitate and mob-like; in the basic concept of [7] crowds are classified depending on the related situation – casual, protest and scheduled crowds.

Typical characteristics of crowds are intentions, dynamic, size, density, location and time interval of the crowd situation. Another typical feature of a crowd is that the behaviour of each participant affect the crowd behaviour in a nonlinear way. In [10], this phenomenon is named collective intelligence. It can explain how choices of each individual for its path, speed, direction can be affected by the crowd. For example, individuals that do not want to be part of a crowd choose less crowded paths. On the other hand, some people might actually be attracted by the crowd, hence their behaviour will most likely be change to match the crowd's behaviour. Crowd properties and their definitions are illustrated in Figure 1. Good knowledge of crowd properties is not only required for proper crowd management, but it can also be crucial when ensuring crowd safety. For example, according to information provided in [9], typically, one square meter is occupied by 2.14 number of persons if they are walking and by 3.75 when they are still. The maximum allowed density of people per square meter should be six persons. However, once the persons per square meter become about 4 or 5, the risk of rapidly built congestion increase [11].

Estimation of all characteristics of the crowd, analyzation of crowd behaviour and actions taken to manage the crowd are known as CM. The workflow of CM is to manage to collect data from peoples and sensors, to analyse and process the data in order to obtain useful information which can help control the crowd and ensure people's safety and satisfaction.

As defined in [7], CM is a set of measures that must be taken to facilitate the movement and enjoyment of people. CM usually takes into account all available crowd-sensed data, analyses it and translates it into predictions and actual actions. The aim as per [8] is to develop infrastructure that can effectively manage crowd at any time. Main tasks performed by a CM system include the location of the place where the gathering occurred, performing noise control, communicating with the crowd if required, planning different possible scenarios of a crowded event, get to know the purpose of the event. Another definition of CM, provided by [12] claims, is the "ability to monitor and, where necessary, direct a group of people to ensure their safety."

Size	Determined by the number of entities in the crowd. Entities might be people or vehicles
Density	Amount of crowd entities which occupy one square meter
Location area	Area where crowd is currently located
Speed	Crowd can be either static (having speed approximately equal to 0) or dynamic.
Crowd intentions	Intentions behind crowd formation
Time interval	Time period during which the crowd exists
Direction	In case of dynamic it is the direction of the crowds
Collective intelligence	Functional behaviour of the crowd which is an effect of the nonlinear interactions of individuals, instead of individual reasoning or global optimization

Fig. 1: Characteristic Properties of the Crowd

A. Available Crowd Management Solutions

CM can be successfully applied in different areas of life. Implementing CM solutions brings intelligence to every event and increases the the safety of event participants. In this section, we will describe the most common areas where CM solutions can be applied. Figure 2 illustrates the key areas where CM solutions can be used.

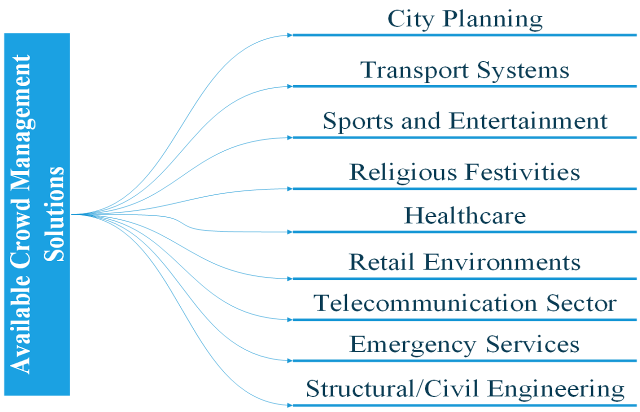

Fig. 2: Available Crowd Management Solutions

1) City Planning: Cities are constantly expanding and evolving, citing challenges to city development and management plans. Thus, sustainable city planning and providing for requirements are critical global challenges [13] to avoid infrastructure problems in the future. CM provides efficient city planning and management solutions through monitoring and analyzing daily traffic and population movement. CM solutions show how statistical survey and dynamic sensing data can help city management estimate the resource requirements in suburban areas [14] through crowd prediction and evaluation in city exteriors.

2) Transport Systems: One public system that can benefit significantly from CM is the transportation system. Both pedestrian and vehicle traffic management can take advantage of CM; for example, using IoT solutions available in smart cities, traffic can be analyzed and optimized. Transport and traffic management can utilize crowd management technologies, such as IoT sensors from mobile operators, to overcome challenges like congestion, pedestrian flow management, road accidents, etc. [12]. Congestions can cost up to $160 billion in lost productivity. AT&T Labs, in cooperation with the University of California at Berkeley and the California Department of Transportation, can significantly improve urban planning using aggregate and anonymous cellphone data [12]. CM is considered a fundamental block of any intelligent transportation system, pointing out that it can provide management of the people in indoor areas - airports, stadiums, and shopping centers [15]. Grid 360 [12] was deployed by StarHub organization in Singapore to collect aggregated and anonymous geo-location data to examine and understand travel patterns and crowd densities.

3) Sports and Entertainment: Entertainment and sports like music festivals, cultural, indoor and outdoor sports events, museums, and nightclubs can utilize CM technologies to manage crowds and ensure safety and a satisfactory experience. Real-time monitoring and statistical data collection at events can help manage and plan future events. Orange Belgium has deployed a CM solution for hosting local events in collaboration with local service provider Cropland and the City of Antwerp [12].

4) Religious Festivities: Religious festivals (like Hajj at Makkah and Kumbh Mela at Allahabad, India) tend to gather mass groups of people in a specific location and are one of the riskiest crowded situations. Religious festivals gather pilgrims on different sites for a short period. Crowds are usually massive and dense, moving to a specific sacred location or performing movement rituals, making them vulnerable to security issues, stampedes, trampling, congestion, and even fires [9]. CM can be helpful in monitoring and adequately managing such events are crucial for the crowd's safety to prevent tragedy. CM Solution for monitoring pilgrims [11] consists of smart infrastructure - video surveillance management system, real-time AI video analytics, and integrated command and control system. The real-time analytics processing system receives video streams from 41 high-speed cameras. It uses AI and deep learning approaches to provide data analyses and reports for crowd density, size, and direction.

5) Healthcare: Smart wearable devices can be attached to patients, thus providing real-time information to doctors. Health status and indicators such as body temperature, blood pressure, saturation, movements, and even speech can be monitored by doctors [16]. Crowd monitoring systems can also provide online consultations with doctors. Infrared camera monitoring can show people's temperature and identify sick people. This is a critical point during a pandemic situation where the entrance of buildings, offices, and even countries should be carefully managed. Once a sick person is identified, records from the CM system can also be used to find their recent contacts.

6) Retail Environments: Retail environments can leverage accurate positioning data for both planning and effective merchandising. IoT sensors from mobile operators help retail managers observe how people move around the shopping area, which is the most visited sectors, and how promotions and advertisements persuade people to choose one shop over another. In supermarkets, for example, this information can be used for a better arrangement of goods based on customer's shopping habits or for opening of additional check-out points on demand.

7) Telecommunication Sector: The telecommunication sector encounters difficulties in highly dense situations and suffers congestion and breakdowns. Shortage of resources causes service denial to some users in the crowd. Integrating mobile devices to make them participate in service/data provisioning using the cloud, fog, and edge computing technologies can minimize service denial situations [17]. CACROM architecture ensures available telecommunication support in critical scenarios, and the data collected during crowdsourcing is valuable for better planning and optimization of telecommunication network resources. CM provides a vision for the data flows and changes in user demands during different parts of the day and other parts of the city.

8) Emergency Services: CM can be beneficial in providing Emergency services in large-scale emergencies and disruptive scenarios, for example - mass shootings, an earthquake, blizzards, hurricanes, terrorist acts, wildfires, etc., to minimize the risk to human life. Communication Architecture for Crowd management (CACROM) [8] provides communication services in emergencies and consists of a power segment, communication segment, crowd data collection, and notification segment. Analysis of people flows in each public and crowded zone can help design emergency evacuation scenarios.

9) Structural/Civil Engineering and Building Services: Characteristics of crowds and people flows can be beneficial for structural and civil engineering to provide building services. For example, helpful information for the design of shopping centers is how long it takes pedestrians to get tired and end the shopping process, which can be used to calculate shop rentals depending on how close they are to the shopping center entrance. Similarly, emergency schemes in each building can also be designed more precisely if crowd management is considered. Pedestrians' free speed usage of stairs and ground varies depending on people's age, gender, and geometry [18].

B. Building Blocks of Crowd Management System

Different variations of CM system building entities can be found in the available literature. For example [12], collection of data and notifications to users are united in one segment - Crowd Data Collection and Notification Segment. The proposed structure of the CM system [15] is composed of Crowd Monitoring and Crowd Control blocks – the first is responsible for Data collection and Information/knowledge extraction, and the second for decision making and control. A different structure is proposed [19], where the first module of the system is related to monitoring and collecting data only, the second one is responsible for validation and correction of collected data, and the final 3rd one is responsible for analysis. A Diagram of the proposed structure of the CM system by this article can be seen in Figure 3.

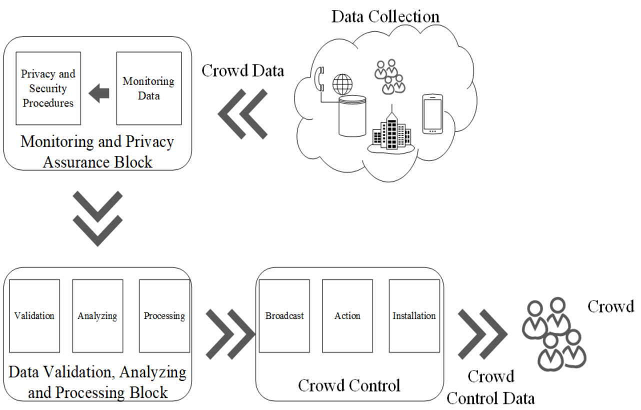

Fig. 3: Building Blocks of Crowd Management Systems

1) Crowd Monitoring and Privacy Assurance Block: This block is responsible for crowd sensing and monitoring as well as privacy and security of collected data. It includes Crowd monitoring, a process of collecting data related to the crowds, using different sources such as smartphones, surveillance cameras, road sensors, wireless sensor networks, Closed-Circuit Television (CCTV), Radio Frequency Identification (RFID) such as event tickets, event-distributed id tags, social networks, microphones [7], [19], [20].

One of the main tasks of each CM is to define sources it will use in the management process. Using the most suitable sources of information will enable better observation and examination of the crowd. Understanding crowd mobility dynamics will help to fulfill the goal of the CM system - for example comprehending and control the spread of infectious diseases in urban areas, assist network infrastructures in providing better distributed services with guaranteed QoS and QoE in public and private spaces, optimize the transport sector. An interesting classification of crowd data collection approached with three base groups is proposed [12].

2) Crowd Data Validation Block: This block is responsible for data validation and aggregation of crowd data collected. It includes (1) Data Validation and (2) Crowd Situation Detection. In data validation, collected data is provided as an input to be tested against different algorithms related to data processing, anomaly detection, verification, and correction algorithms. It also checks for fake or malicious data [20]. Crowd situation detection provides real-time event detection and statistical reasons after certain events. Detection is usually performed on unplanned events.

3) Crowd Situation Analysis and Processing Block: This block performs crowd prediction and analysis and provides input to the Crowd Control (CC) block. It is responsible for (1) Risk Evaluation (RE) and (2) Prediction of Crowd Dynamics. RE is an essential part of crowd analysis to avoid tragedies and emergencies. Knowing the exact time when a crowd becomes risky and taking preliminary measures can ensure the safety of all participants in the crowd.

4) Crowd Control Block: This block is responsible for sending feedback to the authorities responsible for crowd management to alarm unusual activity in crowd behavior [7], [8]. CC can be performed through fixed or removable barriers, different signs, or even IoT – for example, providing route suggestions, coupons, and information concerning relief goods. Self-organizing mobile edge arrays can also be used to sense and visualize crowds in urban areas. Such a visualization shows where there is a need for additional resources [14].

III. Metaverse Crowd Management

The Metaverse is still in its infancy and figuring out its requirements and utilities. Evolving network architectures and the IoT over 5G/6G network can provide lower latency and faster download speeds for remote access and data exchange between the two spaces [21]. The advancements in immersive technology can provide the horsepower needed for high-performance processing in the Metaverse. AI/ML can enable the Metaverse's potential through intelligent avatars and digital twins and the comprehension of natural languages to facilitate human-machine communication and learning [22].

The Metaverse platform will be beyond physical boundaries and, thus, demands high-security means. Identities of the users will comply with the permissions at various levels based on the task and application. Avatars representing the user in meta-space creates a virtual crowd and will play a significant role in providing services and experiences.

Metaverse Crowd Management (MCM) will include avatar movement, choice preferences, location tracking, etc., same as in physical scenarios. CM will be significant in Metaverse in planning events and the marketplace. It will enable users to feel more connected to one another by allowing geographically separated participants to participate in realism- and spatially-aware experiences that seamlessly integrate virtual material into a user's physical surroundings. Industries are pacing up for the Metaverse, estimating customer needs requirements and analyzing strategies to lure more customers with the CM solutions and surveillance.

IV. Integration of AI in Crowd Management

AI has found its implementation in nearly all industries. It will be essential in CM to streamline and advance how people manage populations and crowds worldwide. How we organize, encounter, and meet has changed due to technology, from cities to events and the pandemic. While AI may support, automate, and enhance planning and decision-making, it is only one solution component. When it comes to CM, machines can evaluate photos from cameras, traffic, or crowd motions and behaviors, but there is still much human work to be done. [23] AI algorithms will evolve from invoking learning using thousands of well-chosen photographs/videos to identifying crowd sizes, behavior, and movements.

The authors in [24] evaluated some notable, crowded occasions when the pandemic occurred. Using AI/ML, they created a framework for acquiring the ability to manage packed gatherings efficiently. The authors [25] developed an AI-based solution to accurately estimate the number of people in diverse imagery in real-time. The variations of appearance, perspective, illumination, crowd density, and distribution challenge the crowd counting task. It also affects the system's performance in terms of speed and accuracy.

V. Challenges and Opportunities

In this section, we will highlight key challenges in identifying, describing, and analyzing a crowd in a city. Some of the challenges and opportunities are illustrated in Figure 4 and are described as follows [26]:

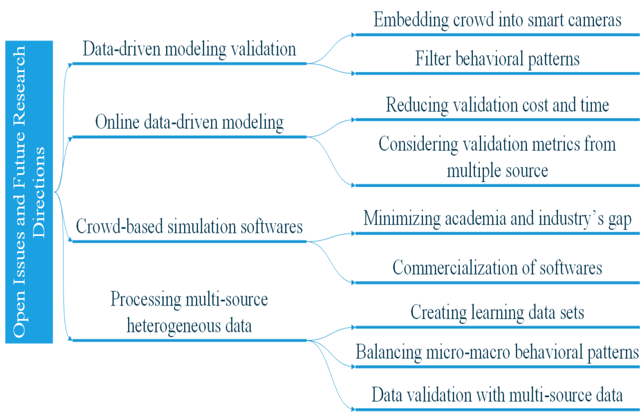

Fig. 4: Building Blocks of Crowd Management Systems

A. Data Processing

As we deal with significant data volume, diversity, and velocity, data management demands scalable and distributed solutions based on high-performance computational architectures. The collected have limitations, such as a small number of users being watched at a time and restricted temporal and spatial coverage. Combining several data sources can help solve these issues and improve representation by enhancing their scale, spatio-temporal accuracy, and semantic content. To address the problems with data quality, data imperfection, outliers, contradicting data, and data sparsity that arise in crowd management utilizing urban data, heterogeneous data fusion is a potential technique.

B. Privacy and Security

The collected data are typically closely tied to human involvement; as a result, it is essential to protect people's security and privacy. On the other side, we must encourage their engagement and make data accessible to the general public while protecting their security and confidentiality. Depending on the data type, some solutions are based on anonymization, multiparty computation, and data perturbation, but they fall short of ensuring privacy without compromising data quality.

C. Adaptive and Interactive Crowd Simulation

In order to learn dynamic pedestrian features and to produce realistic crowd movements at interactive speeds in dynamic surroundings, statistical techniques to forecast and calculate the crowd's movement patterns from the surveillance films may be crucial. Additionally, by constructing pedestrian behavioral trajectories, advanced computer vision and tracking techniques can be employed for data-driven crowd simulations [27]. Using trajectory data from multiple crowd recordings, authors in [28] have adapted the simulation to a dynamic setting with varied pedestrian movement patterns.

VI. Conclusions

For safety or efficiency reasons, large crowds of people frequently increase the need to comprehend and optimize their flow. Queues at entrances or counters for large events, in a store, or on a public transportation system are examples of scenarios. For existing crowd management strategies to be successful, real-time data is required. Since the counting is done manually by individuals or estimates, this data is frequently inadequate. Additionally, there is no information available regarding the crowd's flow, confluence, pace, or movement. The ability to predict flows and use data-driven indicators as the foundation for control measure decisions is considerably aided by understanding people's movements and locations. Using GDPR-compliant sensors with AI capabilities to visualize people's flow and space use. Events can be set off by bottlenecks or rapid flow changes to enable quick response.

With the emergence of Metaverse, interactive data-driven CM solutions can provide the retailers, gamers, Organizers, realtors, etc. a base to develop and launch their solutions and products depending on the crowd's behavior patterns. It might potentially cause a lot of privacy infringements like data surveillance, inferencing, predictive privacy harms, anonymization, etc. It can potentially track data to draw conclusions that lead to erroneous user descriptions or share sensitive and personal information generated by a predictive model with advertisers via the Metaverse would worsen various personal problems.

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