Perspectives on Intelligent Transportation Systems Future in Mecca Area

Mahmoud Owais
Civil Engineering Department, Faculty of Engineering, Assiut University, Egypt

Abdullah Alshehri
Department of Civil Engineering, College of Engineering, Majmaah University, Saudi Arabia

ABSTRACT
The Holy City of Mecca is the place where millions of people gather for religious rituals over the year, and despite the enormous administrative efforts directed to the administration of Congestion Management (CM) during the Hajj and the "Al Mashaaer days", there is always the possibility of introducing better services in subsequent years. This study has a practical outcome in this respect, as it aims to develop a methodological framework that can operate as a supportive tool in the administration of the Hajj, thus easing the movement of pilgrims in congested areas. The methodology acknowledges that the major areas of mobility in Mecca seem to be repetitive, with the leading destination being the Al Kaaba area and particular locations (hotels) being targeted at certain times (Prayer times). To support this mobility, the users and the drivers should be connected via a single platform based on an Artificial Intelligence algorithm (Reinforced Learning, for example). Such a strategy would optimize mobility in the area over time by learning from actions/decisions such as ridesharing matching, taxi dispatching, en-route guiding, and the generation of intermodal paths. That would help in providing solutions for real-time interaction. Decisions about departure times, paths to follow, modes of travel, and logistic freight movement would be available for all.

Keywords
Congestion Management (CM); MaaS (Mobility as a Service); Ride Sharing; Smart Mobility; Intelligent Transportation System (ITS); Mecca Area; Pilgrimage

1. INTRODUCTION
Congestion Management (CM) has been stated as an essential part of modern transportation networks [1]. The CM aims to provide alternative means of transport and route options in real-time since this would be more effective in dealing with congestion problems [2, 3]. These studies pointed out that such transport alternatives could include taxis, transit, bicycling, and even easy paths for walking. However, probably the most popular and indeed dominant forms of transport in many places worldwide are cars, and this results in heavy traffic congestion and air pollution in big cities, which affects everyone within these places [4, 5]. As a partial remedy, many researchers [6, 7] have identified Mobility as a Service (MaaS) and Ride Sharing as one of the most effective solutions in the different CM paradigms. These approaches for mobility services are now discussed as possible sustainable solutions for transportation planning, promising to improve traffic management and lessen congestion [6, 8].

MaaS can offer travelers access to several modes of transport without the need to own any vehicle, thereby presenting travelers with seamless and carefree traveling [9, 10]. Ridesharing also helps mitigate traffic congestion and can provide increased flexibility and comfort that traditional public transport services alone have difficulty achieving [11-13]. Hence, both strategies foster a modal shift away from private car usage. It has been pointed out that transportation solutions should be addressed from the destinations' viewpoint, specifically regarding how they can be reached within options of optimum routes and alternative routes [14, 15]. Consequently, the desired path(s) should be measured first and then route directness determined, taking into account factors like the shortest and/or the fastest option. In addition, transport equity in terms of costs and delays are also issues that need to be addressed in transportation planning [16-18]. Considering these factors, it is possible to obtain better CM solutions [19-21]. Furthermore there are some other related issues that should also be addressed when aiming for improved CM, and these are summarized in Fig.1.

MaaS and ride-sharing do not represent a traditional emerging business model but rather a multimodal business model of intelligent transportation systems (ITS) which is co-created by a network of actors [22-24]. This model emerges at the intersection of several concepts and ideas, multiple business models, and technologies. Its core characteristics are customization and personalization, an all-in-one mobility market platform, resource sharing, and replacement of the private car. ITS deployment is rapidly increasing globally. It encourages the use of communications technologies, and the widespread utilization of technology enablers, such as smartphones, is creating new opportunities in ITS and providing impetus to the deployment of ITS projects. Individuals and vehicles are increasingly being equipped with technologies capable of monitoring their movement, leading to an increased understanding of individuals' mobility needs, resulting in improvements to transport planning [25-27].

2. AIMS OF RESEARCH
In the Mecca area, movement is seen across the three main cities of Mecca, Jeddah, and Madinah, and this holds with respect to both people and goods but is at its most challenging during the pilgrimage season. Moreover, it is expected that the number of pilgrims is above 10 million in 2030, representing a vast gathering of individuals making their way to and from Mecca City alone [28-31]. The safety of this enormous volume of people, traveling either on foot or riding in vehicles to perform their religious rituals, depends upon the continuous moving of the throng. At present, it causes huge congestion. What is interesting, given this situation, is that there are relatively few studies concerning smart mobility in the Mecca area, and those that have been undertaken have not focused on tackling the challenges of finding smart solutions that are applicable in real time [32-34].

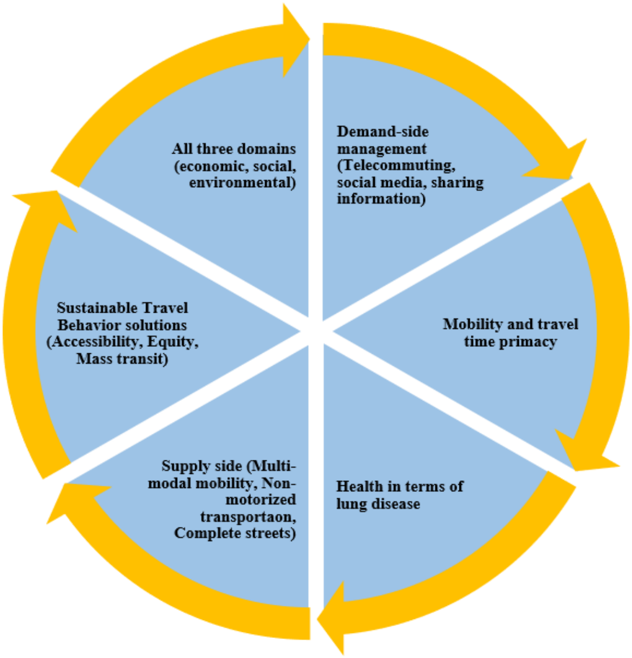

Fig. 1: Crowd Management Objectives

The authors of this article believe that Mobility as a Service (Maas) and Ridesharing are concepts that could be suggested as novel smart solutions in the area of multimodal Intelligent Transportation Systems (ITS) [35, 36]. These two concepts are new in the real practice as ITS and are currently being made available in the form of mobile Apps like Whim. However, the innovation producing intelligent mobility services depends not only on the advanced planning of transport means but also on the sharing of dynamic information by users, such as their position and number, the modes of transport available, their position, and occupancy. The proposed Artificial Intelligence (AI) programming and the algorithms should work together to expand the size and range of the offered mobility options by integrating all forms of transport - public transport services, taxis, ridesharing facilities, and walking options in a single framework [37-39]. This would present passengers with the features of a well-planned journey, advance booking, and online payment for the whole journey with several transport modes in one service (app).

Also, this article's perspective matches with the Saudi Arabia 2030 Vision that one of its principal objectives is "to serve the number of Hajj and Umrah visitors in the best way possible with complete satisfaction and experience". In this respect, the study aims to provide a general framework to develop integrated algorithms that can offer solutions to the Mecca area in terms of the ITS paradigm. It can help IT programmers and developers to create a smart IT application using Maas and Ride Sharing network services following the concepts illustrated in this article. The outcome will be that Hajj and Umrah visitors can experience greater enjoyment on their spiritual journeys than at present [40, 41].

3. METHODOLOGY

Artificial Intelligence (AI) has emerged as a powerful tool for solving intractable problems, and hence, its intervention in all applications has become inevitable [42-44]. AI has enabled planners to mimic user reactions to a provided service over time [45, 46]. Deep learning can be used with respect to traffic prediction, thereby making for a general easing of CM decisions in the short term [47, 48].

Generally, CM aims to enhance people's mobility, which is a measure of transportation system effectiveness, defined as the average travel time (hour) per ton-mile required (TMR) obtained from a geographic distance. We redefine a new computation model for the Mobility (M) to suit our case as follows:

$$M = \frac{\sum_{(i,j,n,\bar{t})\in R} p_{i,j,n,t}\, T_{i,j,n,t}}{\sum_{(i,j,n,\bar{t})\in R} \bar{T}_{i,j,n}} \qquad (1)$$

where; R is the set of all city trips (made by the crowd). An origin-destination pair (O-D pair) is described by (i, j), where i is the index for origin, j for destination, $p_{i,j,n}$ is a penalty for the late departure of the trip (i, j, n) from the required departure time $\bar{t}$. $(i, j, n, \bar{t})$ represents a single trip, and n is the index of trip repetition for the same O-D pair (i, j) with the same departure time $\bar{t}$. $T_{i,j,n,t}$ is the planned travel time for the trip (i, j, n) with the new departure time t. $\bar{T}_{i,j,n}$ is the best theoretical travel time for the trip (i, j, n) in the desired departure time $\bar{t}$. It is clear that the optimal value for M = 1 means that every individual will depart on time and reach his destination in the fastest way [49-51].

Pilgrim data, experience, and the demand for moving are considered as the raw variables that must be relied upon to support the decisions and policy planning in the proposed methodology. Because of computers and new technologies, data storing, recalling, and analysis became largely increasingly unexpected. The massive amount of data can be confusing to use, but it can be used by implementing AI techniques to build a great system to draw the plans and outlook for the pilgrim's future policy and their needs, see Fig. 2.

One of the AI algorithms is the Reinforced Learning (RL) algorithm, which can learn from the existing state over time to optimize its future decisions. Many successful applications have resulted after being proved by the RL algorithm [52, 53], which suggests there could be promising results with respect to the proposed project. For example, the optimal Mobility state ($V(s^*)$) can be deduced after several trials using the (RL) technique as follows:

$$V^*(s) = \max R_s^a + \gamma \sum_{s' \in S} P_{ss'}^a\, V^*(s') \qquad (2)$$

Where; $V^*(s)$ is the optimal state-value function (the optimal M value overall policies), R is the reward function, S is the set of states for every state (s), a is the action (mobility plan) taken by the AI in the learning stage, and P is a state transition probability matrix to represent the uncertainty existing in the real world. This methodology may incorporate two levels of decisions: real-time decisions, which may depend on a greedy method to obtain a rapid response, and decisions that come from learning that are being optimized over time. Eventually, the AI methodology would learn the optimal CM rules required to control the assignment of available transport supply modes to the users [54, 55].

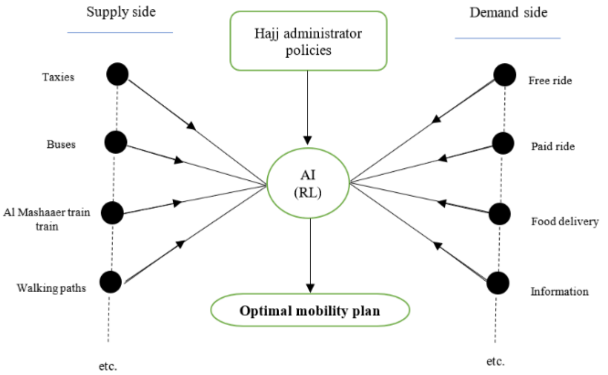

Fig. 2: Artificial Intelligence Implementation in the Hajj Crowd Management

4. RESULTS AND DISCUSSION

As already mentioned, we aim to adopt dynamic information exchange to expand the size and range of the mobility services currently offered, thereby alleviating traffic congestion. So, four research questions are formulated, these being:

- How can the proposed methodology's architecture and functions model the study objectives?
- What are the novel crowd management functions for both passengers and operators?
- What data structure is needed, and how is it related to the functions?
- What functions are needed?

The proposed framework is comprised of three consecutive stages: the first is a field survey conducted in the Mecca region to collect the required information about the existing infrastructure; the second is the theoretical modeling; and the third is the evaluation stage of the expected scenarios during the pilgrimage and Umrah periods. In the first stage, a detailed survey of the city of Mecca will be undertaken to collect the required information about the existing transportation infrastructure, the expected number of pilgrims for next year, the existing CM plan, and the additional facilities that can be provided. In the second stage, the data will be processed, as indicated in the subsequent paragraphs, to obtain the best scenario for crowd management and thereby equip the Hajj administration with answers to questions regarding how to ensure safe travel for pilgrims in the actual event. These answers will address questions concerning departure times, paths to follow, available riding modes, and freight movement logistics. In the final stage, the results will be compared with the existing Pilgrimage crowd movement scenario to judge the methodology's efficiency. It is worth noting that the proposed algorithms could be initially optimized via simulated networks. In short, we could summarize the project framework as depicted in Fig. 3.

The expected outcome is that the findings will engender an innovative, intelligent mobility solution, which is now discussed as a possible strategy to manage the problems experienced in the present traditional transportation system when pilgrimage tourists congregate at Mecca and when movement within the area cannot be promised with seamless, carefree, and easy access to multiple transport means. In addition, if intelligent mobility proves itself, it can rapidly encourage users and help the local transport authorities of Mecca to understand the broader potential of the solution to improve transportation management by creating, for example, a user-centric receiver generating transportation data so that intelligent mobility planning and controlling can be produced which can then become a component part of an integrated, and widely usable system. Furthermore, regarding the scientific outcome, we aim to secure a patent for a piece of user-friendly software based on our methodology. The study will also help meet the aim of providing fully automated services via integrating e-services regarding the journeys made by pilgrims to the Kingdom. The Vision aims by 2030 to make it possible for over 15 million Muslims per year to perform Umrah and be completely satisfied with their pilgrimage experience.

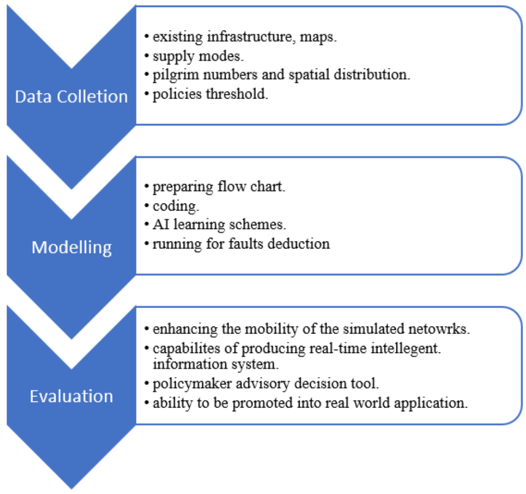

Fig. 3: The General framework to convert the Mecca area into ITS

The proposed framework will be part of a comprehensive and integrated initiative initiated by the Ministry of Municipal and Rural Affairs (MMRA) to achieve the Smart Cities Concepts referred to in the National Transformation Program 2020 and the Kingdom's Vision 2030. In this respect, the MMRA has pointed out in a study entitled "Study Components of Smart Cities" that the concept and components of the 'smart city' will be initiated in five Saudi cities by 2020 in partnership with the private sector. That particular study has indicated that the City of Mecca is in the first in terms of readiness to embark upon this transformation. Consequently, the focus on Intelligent Transportation will be inspirational in effecting the digital transformation set in the Kingdom's Vision 2030. Inevitably, improved regulations will result, and effective partnerships will be created with transportation operators.

Finally, the proposed framework will push for a collaboration between the public and private sectors, each of which would be acknowledged to play a crucial role in the ongoing direction to convert Mecca to a smart city for the benefit primarily of pilgrims but also of all citizens.

5. SUMMARY AND RECOMMENDATIONS

The main aim of this study is to propose the MaaS and Shared Riding approaches and establish how they can be utilized in the digital world to produce an On-demand intelligent mobility solution that will improve the current traditional transportation system across the Mecca area. In proposing these approaches, the study presents the mobility issue (embracing all means of transport) brought by pilgrims when traveling to and leaving the main Mecca metropolitan cities (Mecca, Jeddah, and Madinah) for their Hajj and Umrah visits. These two approaches are demonstrated in the literature and authentic theoretical framework studies to provide users with easy, seamless, and flexible mobility. They also would deliver significant improvements by reducing heavy traffic congestion stimulated by people using their own cars and goods transport. This study encourages the collaboration between members of the research side (in the areas of transportation, management, and computer science) and decision-makers in KSA to develop an innovative and single platform as well as proposition of the necessary algorithm equations within that platform which can help in changing the future of pilgrimage tourists' mobility. Further research needs to examine the validity and usability of the proposed approach based on simulation experiments testing as well as practical field testing.

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