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Toward Mobility as a Service in Large Cities

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***Abstract*— Mobility as a Service (MaaS), as a part of the smart mobility paradigm, is recognized as one of the most effective solutions for the congestion management (CM) problem in cities. MaaS is a possible sustainable solution for transportation planning, promising the enhancement of traffic management and the lessening of congestion. 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. This study aims to develop a methodological framework adapting MaaS as a supportive tool to alleviate traffic congestion. 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 the mobility in the area as a whole over time by learning from actions/decisions such as: ride-sharing matching, taxi dispatching, in-route guiding, and the generation of inter-modal paths. That would help in providing solutions for real-time interaction. Decisions about departure times, paths to follow, and modes of travel would be available for all.**

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I. 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]. As a partial remedy, many researchers [5, 6] have identified Mobility as a Service (MaaS) 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 the enhancement of traffic management and the lessening of congestion [5, 7]. 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 [8]. MaaS also helps mitigate traffic congestion and can provide increased flexibility and comfort that traditional public transport services alone have difficulty achieving [9-11]. Hence, the MaaS strategy fosters a modal shift away from private car usage. It has been pointed out that transportation solutions should be addressed from destinations' viewpoint, specifically regarding how they can be reached within options of optimum routes and alternative routes [12]. 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 [13-15]. Considering these factors, it is possible to obtain better CM solutions [16-18]. Furthermore, some other related issues should also be addressed when aiming for improved CM, which is summarized in Figure 1.

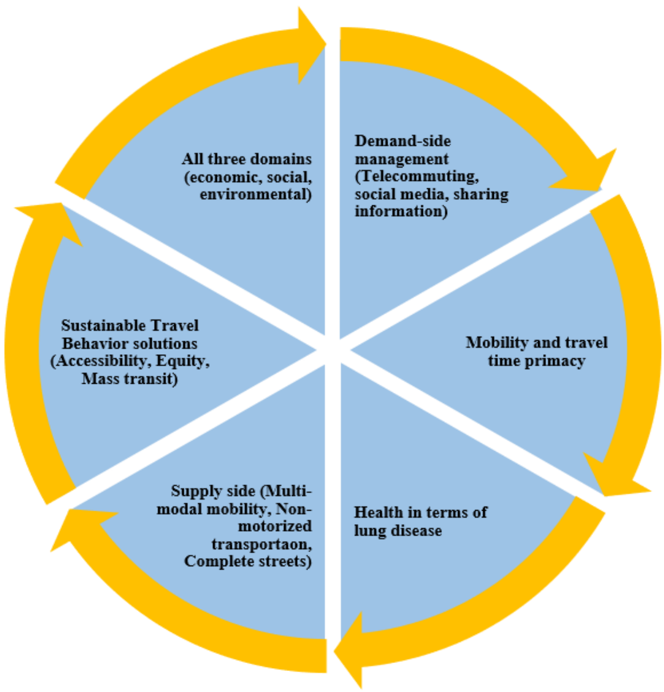

Fig. 1 Crowd Management Objectives

MaaS does 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 [19]. 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 increased understanding of individuals' mobility needs, resulting in improvements to transport planning [20-22].

II. Aims of Research

In large cities, movement is seen across its uninterrupted and interrupted traffic facilities. This holds in respect of both people and goods but is at its most challenging during peak hours. The safety of this enormous volume of people, traveling either on foot or riding in vehicles to perform their daily activities, depends upon the continuous moving of the throng. At present, it causes vast congestion. What is interesting, given this situation, is that there are relatively few studies concerning smart mobility in large cities, and those that have been undertaken have not focused on tackling the challenges of finding intelligent solutions that are applicable in real-time [23-25].

The authors of this article believe that MaaS is the concept that could be suggested as a novel smart solution in large cities for multimodal Intelligent Transportation Systems (ITS). This concept is new in the real practice as ITS and is currently being made available in the form of mobile Apps like Whim. However, the innovation producing the concept of 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 their 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, ride-sharing facilities, and walking options in a single framework [26-28]. 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 the Global Vision of sustainability in transportation. In this respect, the study aims to provide a general framework to develop integrated algorithms that can offer solutions to large cities in terms of ITS paradigms. It can help IT, programmers, and developers create a smart IT application using MaaS network services following the concepts illustrated in this article. The outcome will be that daily transportation network users can experience greater enjoyment on their repetitive journeys than at present.

III. Methodology

Artificial Intelligence (AI) has emerged as a powerful tool for solving intractable problems; hence, its intervention in all applications has become inevitable [29-31]. AI has enabled planners to mimic user reactions to a provided service over time [32]. Deep learning can be used in respect of traffic prediction, thereby making for a general easing of CM decisions in the short term [33].

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

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

where R is the set of all trips (made by the crowd) in the city. 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 trip (i, j, n) from the required departure time. (i, j, n) 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 is the planned travel time for the trip (i, j, n) with the new

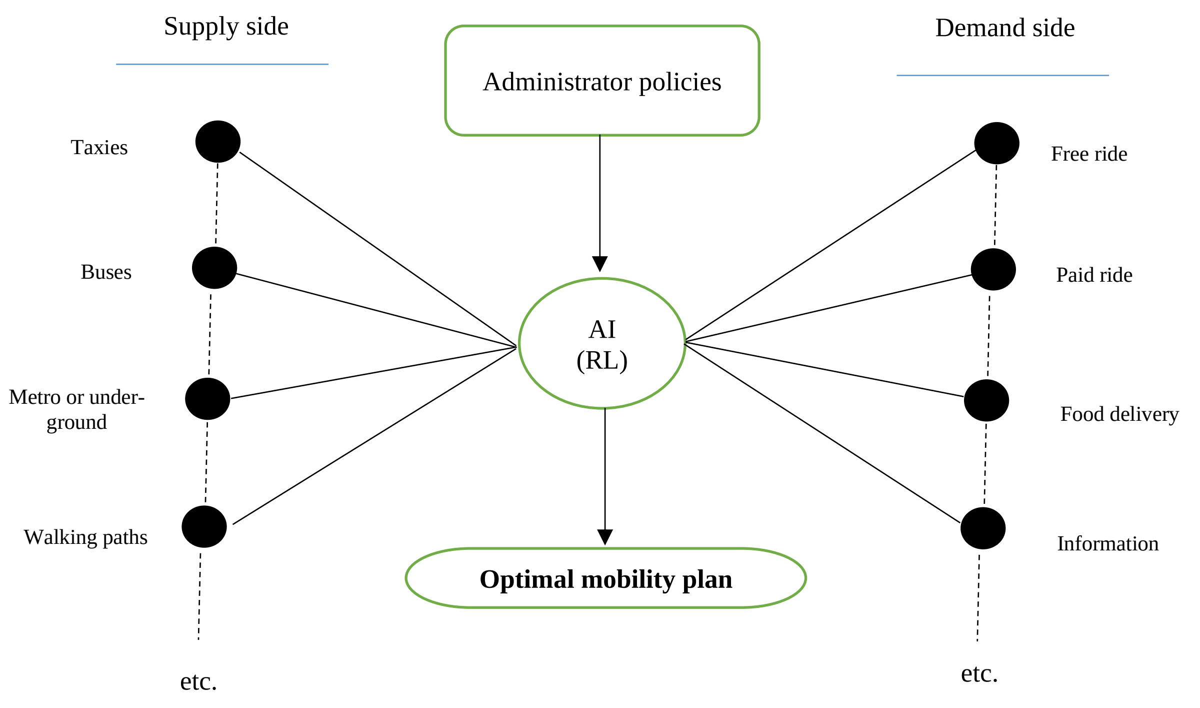

Fig. 2. Artificial Intelligence implementation in the Crowd Management

departure time t.   is the best theoretical travel time for the trip (i, j, n) in the desired departure time. It is clear that the optimal value for M = 1 which means that every individual would depart on time and reach his destination in the fastest way [34-36].

Traffic data, experience, and the demand for moving are considered 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 increasing as unexpected [37]. 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 [38], which suggests there could be promising results in respect of 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), and 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; the first is real-time decisions that may depend on a greedy method to obtain a rapid response, and the second is decisions that come from learning 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.

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

- How can the architecture and the functions of the proposed methodology 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?

The proposed framework is comprised of three consecutive stages: the first is a field survey conducted in the city understudy 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 peak periods. In the first stage, a detailed survey of the city will be undertaken to collect the required information about the existing transportation infrastructure, the expected number of daily users over the period of the analysis, 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 operators with answers to questions regarding how to ensure safe travel for the users 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 crowd movement scenario to judge the methodology efficiency. It is worth noting that the proposed algorithms could initially be optimized via simulated networks. In short, we could summarize the project framework as depicted in Fig. 3.

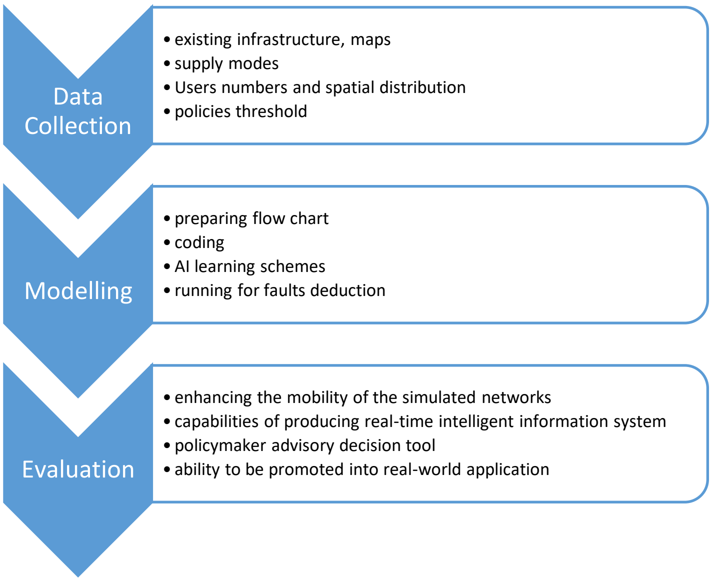

Fig. 3. The general framework to convert a large city area into ITS

IV. Results and Discussion

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 the users in the network and when movement within the whole city 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 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, in respect of the scientific outcome, we target 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 in respect of the journeys made.

Finally, the research 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 a large congested city to a smart city for the benefit of all citizens.

This study would end up with MaaS framework development which is based on an AI algorithm as its backbone. The chosen AI algorithm is Reinforced Learning which enables the developed platform to learn from the repetitive movement patterns of the users to enhance the

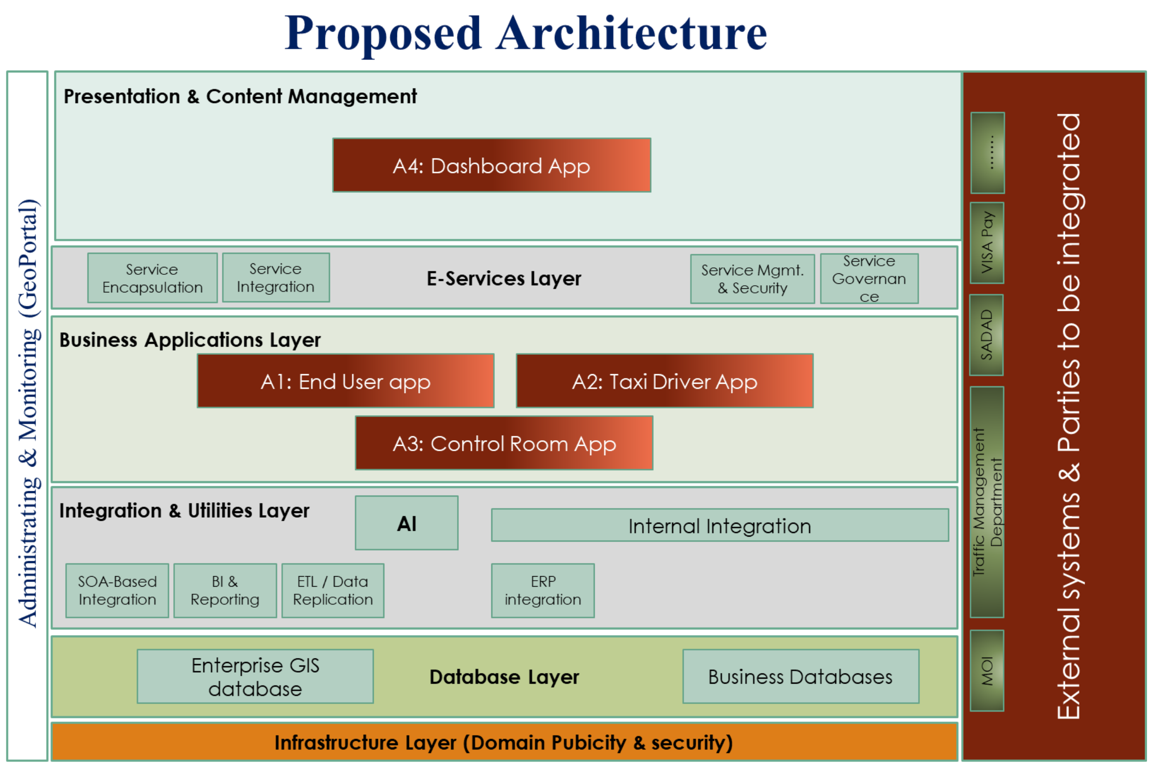

Fig. 4. The proposed MaaS architecture

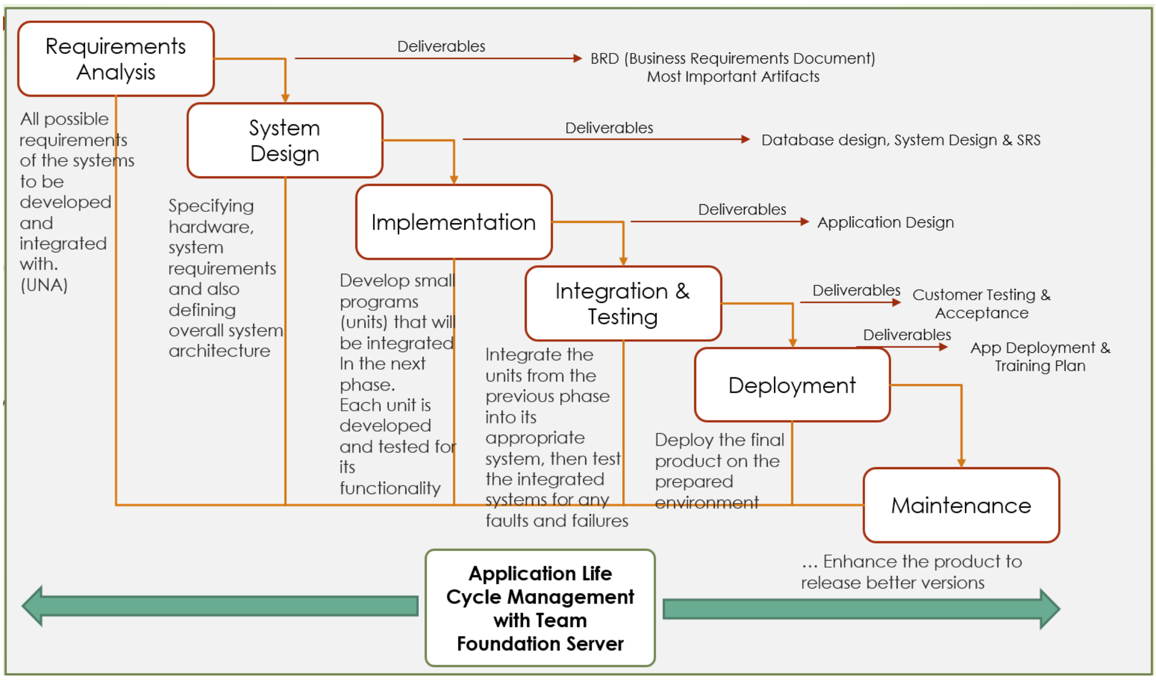

Fig. 5. The proposed MaaS architecture

overall transportation system level of service. Fig. 5 represents the original contribution of this article as the framework that would achieve the vision of this research, whereas the software development cycle is presented in Fig. 5.

V. Conclusion

The main aim of this study is to propose the MaaS to establish how it can be utilized in the digital world to produce an On-demand intelligent mobility solution that will improve the current traditional transportation system across large cities. In proposing these approaches, the study presents the mobility issue (embracing all means of transport) brought by daily transport network users when traveling to and leaving the central network regions for their daily trips. The tackled approach is demonstrated in the literature and authentic theoretical framework studies to provide users with easy, seamless, and flexible mobility. They also would significantly improve 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 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 transport 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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