Smart parking guidance: A step towards sustainable cities

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Abstract- Generally, dense urban areas suffer from local parking shortages: a limited supply coupled with a diffuse demand in both space and time. According to this plan, additional vehicles will be searching for available parking spaces, particularly during peak hours. Searching for parking disrupts the economic, environmental, and social sustainability of the city. The purpose of the paper is to optimize parking management, by guiding drivers who request a vacant space. Multi-agent systems can be used as an appropriate modeling approach for the development of such a smart parking guidance system. In order to verify and validate the model, simulations were performed in Tunis city-center. The numerical results show that smart parking guidance systems can manage parking areas more efficiently. It can reduce energy consumption and carbon dioxide emissions, increase revenues for parking managers and satisfy drivers' requirements.

Index Terms- parking guidance, utility maximization, parking search, sustainability

I. Introduction

It is increasingly difficult to find a vacant parking space within the urban area as most of the transportation infrastructure is over-exploited and under-sized [1]. The mismatch between parking supply and demand [2], caused by a multiplicity of vehicles, the rarity of urban areas, and the under-evaluation of parking pricing, increased the time spent searching for a vacant parking space. A study showed that during peak hours in almost all large cities, traffic generated by vehicles looking for vacant parking spaces can account for up to 30% of the total traffic flow [3].

The conductors do not perceive parking problems, until they are engrossed in the parking search process [4]. However, finding a vacant parking space, who is responsive to our needs, can never be guaranteed due to the lack of accurate information about the spaces, and other conductors. As a result, we exert a lot of effort, but without being effective. Furthermore, even if we simply want to make the best decision, based on the available information, the quantity and diversity of this information (variable message panels, time of day, personal experiences) suggest that the optimal treatment is too complex for our cognitive capabilities [5].

The new technologies of information and communication have been used to solve or mitigate this problem, namely the parking guidance systems. These last systems have been in place since the 1970's [6]. The information they provide facilitates drivers' decision-making processes, enabling them to locate vacant parking spaces around their preferred destinations and to choose where to park [7]. A parking guidance system is most relevant where there is high parking demand [8]. As a result of Southampton's inquiries, the time spent in parking search decreased from 2.2 minutes to 1.1 minutes, courtesy of the guidance system. Dijkshoorn illustrates how the system guides non-habitual drivers (e.g., visitors) toward a vacant parking space, while preventing habitual drivers from viewing already congested parking lots [9]. Thompson et al. developed a behavioral parking model to predict the effect of variable message signs and provide the most effective information for free parking [10]. On the other hand, Shi et al proposed a real time parking guidance system [11]. Conductors can be dynamically regrouped and affect different parking spaces according to their preferences, which prevents the saturation of certain parking spaces.

Liu et al developed a parking guidance system based on the web and a geographic information system (GIS) to let drivers receive information via the internet and mobile phones [12]. At the end of the trip, the conductor can refer to a route map, displayed on his mobile phone, to see which parking spaces are available or who will be released near the destination. Mobilis, Smartphone, Streetline, and Smartgrains are some applications that make it possible for all users to share information about parking in urban areas. The service is provided in real-time. A few studies have attempted to improve parking guidance's reliability. For example, Caliskan et al. aim to improve the availability of free parking [13]. They developed a system for surveying and preserving parking occupancy. The vacant parking spaces were predicted using a Markov model based on the arrival and departure parking times. The utility of the model was demonstrated by simulation tests.

Chou et al utilized an agent-based parking guidance system. Parking can be suggested by drivers based on their proximity to their destination, the parking cost and the capacity as part of the developed system [14]. Although, Seong-Eun et al. presented a conceptual architecture for a parking guidance system based on a wireless sensor network [15]. Through the Internet, users can verify the availability of parking spaces. According to Caicedo [16], real-time parking information could improve circulation by 10%. In addition, Giuffre et al developed a conceptual architecture that provides intelligent management solutions for public parking lots [17]. Model for this study consists of five modules: parking controller, communication module, user interface module, management interface, and function module. This system allows conductors to reserve vacant parking spaces in real-time by using a network of sensors.

Napoli et al. examined the issue of allocating parking spaces based on a negotiation process that creates an agreement between parking providers and parking demanders [18]. The model considered the needs of conductors in terms of parking locations and costs, and the requirements of managers in terms of parking availability and distance to the center of town. They propose a system of information and guidance parking that provides auxiliary users with information about the city's plans and regulations, as well as an estimate of displacement time. An algorithm for intelligent parking guidance was proposed by Shin and Jun [19]. The algorithm allows drivers to identify vacant spaces based on parking occupancy in real time. Simulation tests were conducted. Empirical results show better utilization of spatial resources in cities, a minimization in energy consumption and carbon emissions, and a reduction of congestion caused by parking search traffic. Ben hassine et al proposed a network of intelligent agents that could help drivers to find parking spaces, in real time [20]. The results of this study generated by the platform MATSim transport simulation, demonstrate that their approach optimizes parking lot occupancy. Therefore, Shin et al proposed a predictive control approach based on a neuronal network [21]. The proposed method improves parking guidance's performance via dynamic selection of the best parking spaces. To evaluate of the approach, a simulation test, and a comparison with a traditional model are necessary.

The purpose of this paper is to develop a smart parking system in order to optimize parking management in Tunis city center. Then, we propose a parking guidance system based on real-time parking information to satisfy the needs of conductors and parking managers. The paper is organized as follows. In Section 2, we describe the architecture of the system, the performance measures of smart parking guidance, and the utility function that evaluates the effective parking and selects the best available parking in a dynamic environment. The numerical results and analysis are described in section 3. Conclusions are given in section 4.

II. IMPLEMENTATION ET SIMULATION

Our model simulates the driver's itinerary from his current location to the chosen parking lot, the walking distance, and also the parking cost. Several factors, including walking time, time spent looking for vacant parking spaces, and the parking price and duration, are taken into consideration in the algorithm proposed.

Two environments have been created for studying the effect of guidance on our smart parking system. The first noticed (unguided environment) represents the current parking situation in Tunis city center: an environment without guidance. The second notice (guided environment) described an environment with guidance. A comparison of the two environments has been conducted. To facilitate the simulation process, the underlying hypotheses are considered. Suppose:

- Hypothesis relating to transportation mode: The vehicle is the only dynamic component of our road network.
- Hypothesis about displacement of individuals: this research concerns parking related to individuals' displacement. Parking related to dealer transportation is not covered.
- Hypothesis of parking managers: An organization is responsible for managing all the parking and controlling the parking locations, fees and spaces.
- Hypothesis of the perfect information: Conductors have access to real-time information regarding parking such as the price, occupation, etc.
- Hypothesis of homogenous time value: we suppose that the value of time is the same for all users.

A. Parking guidance system

A smart parking guidance system combines parking demand (destination, duration of activities, and other parameters) with local parking supply (limited parking duration, parking fee, availability of spaces), and treats parking in interaction with the road flow (conditions and traffic state). Our system allocates and reserves a vacant parking space for a driver according to their needs. It allows them to search for available spaces at anytime and anywhere and get valuable information, such as parking names, prices, locations, and costs around their destinations. Furthermore, to look for the optimal path so as to reach the destination quickly, avoid congestion, and ensure parking reservations. Parking decisions vary according to the users. In fact, the driver chooses a parking based on his budget constraints and the level of convenience (parking security, walking time, price). Our smart parking system provides real-time information to the user (Figure 1).

Figure 1. Disposal technique of smart parking guidance system

The parking guidance system will be based on the paradigm of multi-agent systems. A network of cognitive agents is proposed to better assist drivers and parking managers. Adaptability, coordination, communication, and collaboration, allows agents to perform automated searches for vacant spaces, negotiate parking prices, and reserve parking spaces. As a result, intelligent agents select the appropriate parking based on a driver's requirements.

The system consists of autonomous computing units that interact with the environment (infrastructure, parking). It represented the dynamic use of parking resources. Hierarchy is the basic structure of our system. It is through this hierarchical organization that messages can be routed. Different agents from a hierarchical level to another. They are divided into three types based on their characteristics: driver agent, parking agent, and central agent (Figure 2).

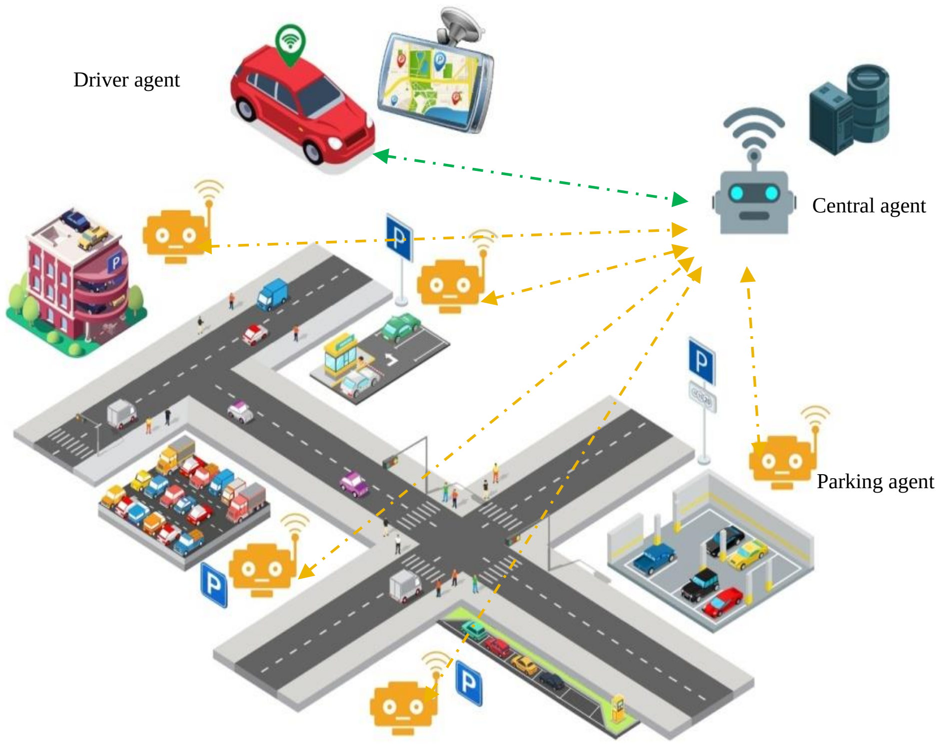


Figure 2. Agents and communication protocol

The parking agents keep all types of information pertaining to their parking lots: type of lot (public or private), location, capacity total, vacant and occupied spots, limited parking duration, rotation rates, etc. Parking agents can predict parking demand in order to better manage the situation. They provide a visual display of historical statistics for periods, for zones or parking lots, and emits a warning when demand is abnormal.

Parking agents are installed in each parking space. In general, they are responsible for tracking parking occupancy at each interval of time. These agents are placed on parking meters signed to on-street parking, as are those in Tunis city center. Alternatively, they can be placed in automatic barriers at off-street parking entrances. The agents will be notified whenever a vehicle arrives or departs from a parking space. They also anticipate the availability of parking spaces, which were used for a limited period of time. Once a reservation is confirmed, the parking agent indicates the occupied new space. Once the parking duration is determined, the parking agent automatically marks the space as available.

The agent central is a server that stores information about parking occupancy and prices for the zone it manages. It provides a general view of all the parking in the area. It provides direct interaction with parking agents through a central supervision entity. It is responsible for acquiring and managing various types of information in real-time. This information is provided by parking agents. For each new contract, it compiles a list of parking with available spaces, around the destination requested by the driver agent. After evaluating the different propositions, it attributes the contract to the winning parking agent, in accordance with the driver agent.

B. Utility Function

In order to simplify the simulation, let's assume displacement generally consists of two steps: First, from the origin point o to the parking j, and second from the parking j to the destination d, for only one activity k. The MATSim utility is defined as follows:

$$U = U_{travel,t} + U_{parking,t}$$

$$U_j^t = U_j^{travel,t} + U_j^{cruis,t} + U_j^{park,t} + U_j^{walk}$$

$$U_j^{travel,t} = \beta_\tau^{driv} \cdot t_{oj}^{driv} + \beta_\delta^{driv} \cdot \ l_{oj}$$

$$U_j^{cruis,t} = \beta_\tau^{cruis} \cdot t_j^{cruis,t}$$

$$U_j^{park,t} = \beta_\mu \cdot s \cdot P_j$$

$$U_j^{walk} = \beta_\tau^{walk} \times t_{jd}^{walk}$$

$$U_j^t = \beta_\tau^{driv} \cdot t_{oj}^{driv,t} + \beta_\tau^{cruis} \cdot t^{cruis,t} + \beta_\tau^{walk} \cdot t_{jd}^{walk} + \beta_\delta \cdot \ l_{oj} + \beta_\mu \cdot s \cdot P_j \qquad (1)$$

With

β_{τ}^{driv} : Marginal utility of travel time
β_{τ}^{walk} : Marginal utility of walking time
β_{δ}^{driv}: Marginal utility of travel distance
β_{μ} : Monetary marginal utility
β_{τ}^{cruis} : Marginal utility of cruising time for vacant parking space
P_j: price of parking j (TND / h)
s: parking stay duration (h)
$t_{oj}^{driv,t}$: driving travel time from the origin o to parking j
t_{jd}^{walk}: time spent walking from parking to final destination (h)
$t^{cruis,t}$: cruising time for parking at time period t (h)
l_{oj} : distance to travel from the origin o to a parking j

III. NUMERICAL RESULTS AND ANALYSIS

As a driver, smart parking guidance should be less costly in terms of money, walking distance, time spent searching for vacant parking spaces, and stress reduction. On the other hand, as parking managers, smart parking guidance should allow optimal usage of parking spaces and maximize turnover. To verify and validate the initial hypotheses, simulations were conducted in a real-world environment, in order to test the impact of smart parking guidance on drivers' and managers' expectations.

Tunis city center is taken as a sample to illustrate the approach. We chose the Tunis city center due to its relevancy linked to the weight of parking supply and demand. The selected zone covers an area of 10 km2. The road network is represented by a diagram of 1361 directed links and 584 nodes. The data set included 346 on-street parking locations with a total capacity of 4,250 places. For off-street parking, there are 24 lots with a total capacity of 4,800 parking spots. The spatial data were edited and processed using QGIS (Quantum Geographic Information System).

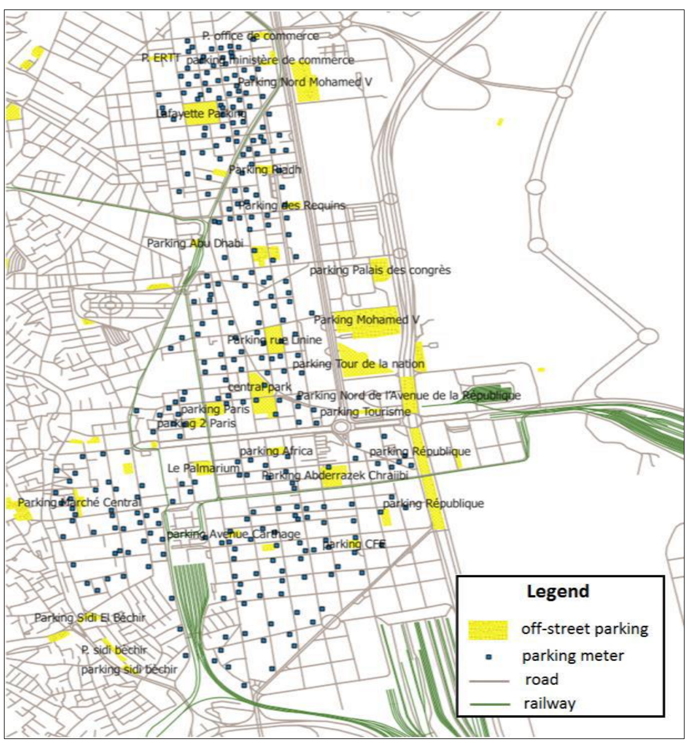


Figure 3. Study area

The simulation concerns a limited time period, typically the morning peak. It is a discrete event simulation with intervals of five minutes. It examines the effects of each environment on: traffic conditions, parking occupancy levels, parking managers turnovers, walking time, travel distance, social well-being, and environmental costs. The simulation reroutes up to 20000 vehicles per day (randomly generated).

A. Traffic conditions

Through simulations, it was shown that parking search traffic is reduced. The road congestion is then mitigated.

A.1. Number of vehicles in circulation

To examine the results of the simulation in both environments, the status of traffic road is compared.

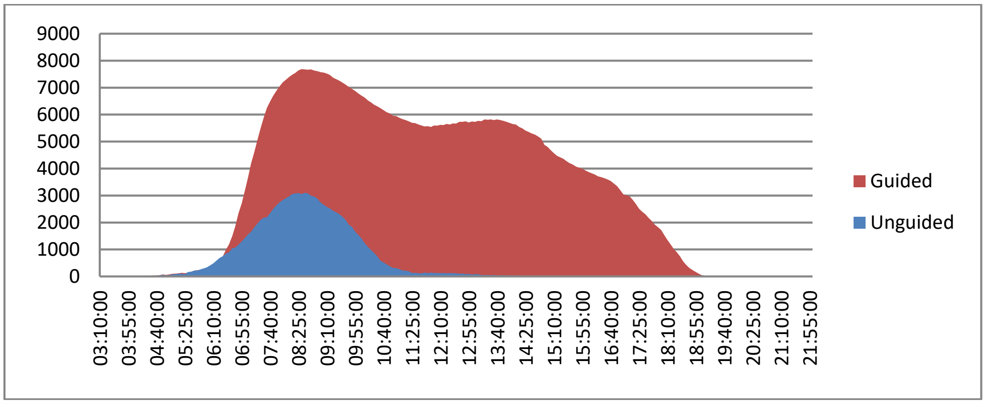


Figure 4. Number of vehicles in circulation

Figure 4 shows the number of vehicles in circulation during simulation day. On the morning debut, the curves have a similar allure. In fact, when parking demand is feasible, all drivers can find an available space that corresponds to their preferences, so there is no additional travel distance. As time progresses, the appearance of courses changes. As a result, parking search traffic is created (unguided environment). Vehicles that are looking for a parking space slow down the movement of other drivers. They generate circulation on the main roads and adjacent streets. The problem is a non-negligible part of traffic flow specifically during peak hours. This is clearly demonstrated in figure 4.

In the comparison of environment (guided) to (unguided), the number of vehicles in circulation is reduced by 15.51 %. These vehicles were looking for vacant parking spaces. The result was as expected. According to a Shoup (2006) study, 30% of the traffic flow can be attributed to parking search traffic. As conclusion, traffic on (guided environment) is proportionally more fluid than traffic on (unguided environment).

A.2. Road congestion status

Figure 5 shows the evolution of road congestion on the day of the simulation.

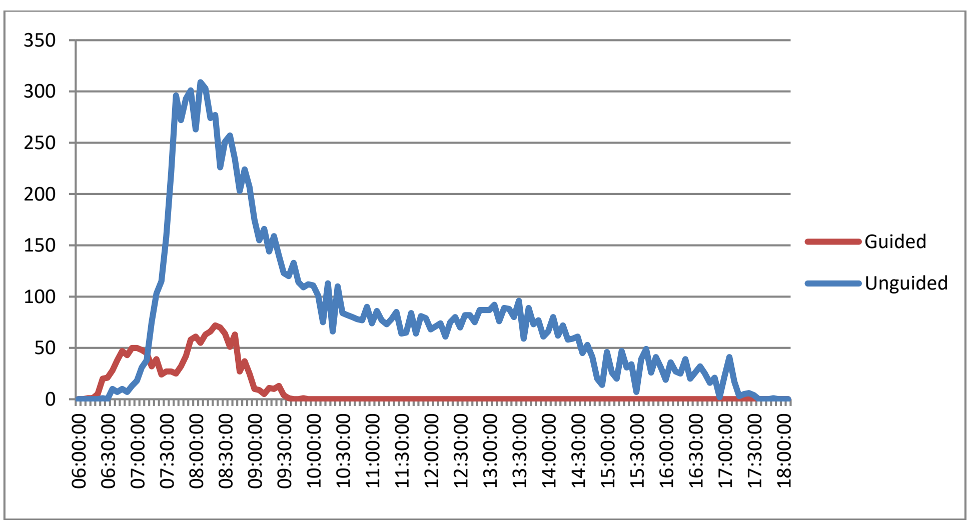


Figure 5. Road congestion status

There are 11918 vehicles for unguided environment and 1421 vehicles for guided environment. Road congestion is then reduced by 11.92%. The reduction can be explained by the suppression of parking search traffic through vehicle guidance. The result proves that traffic is fluid.

A.3. Number of vehicles at destination

Figure 6 represents the number of vehicles that reached their destination.

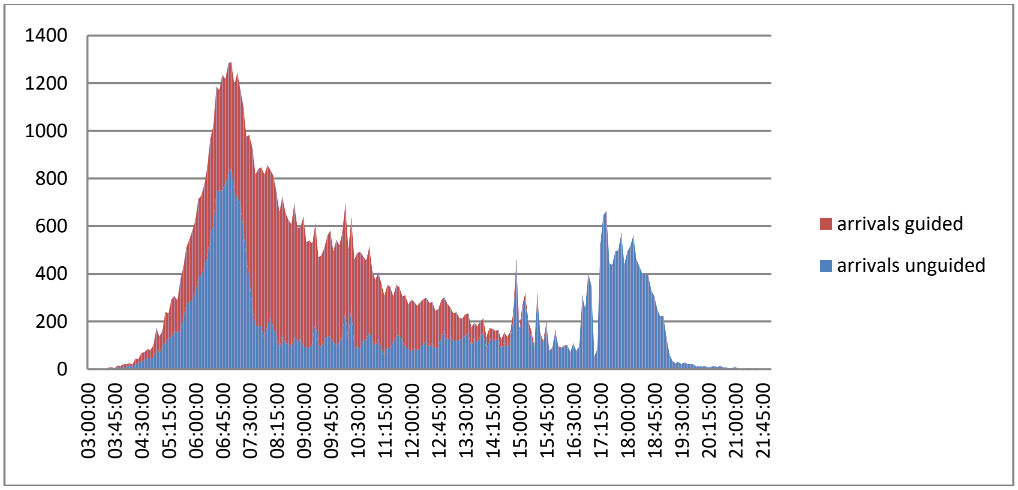
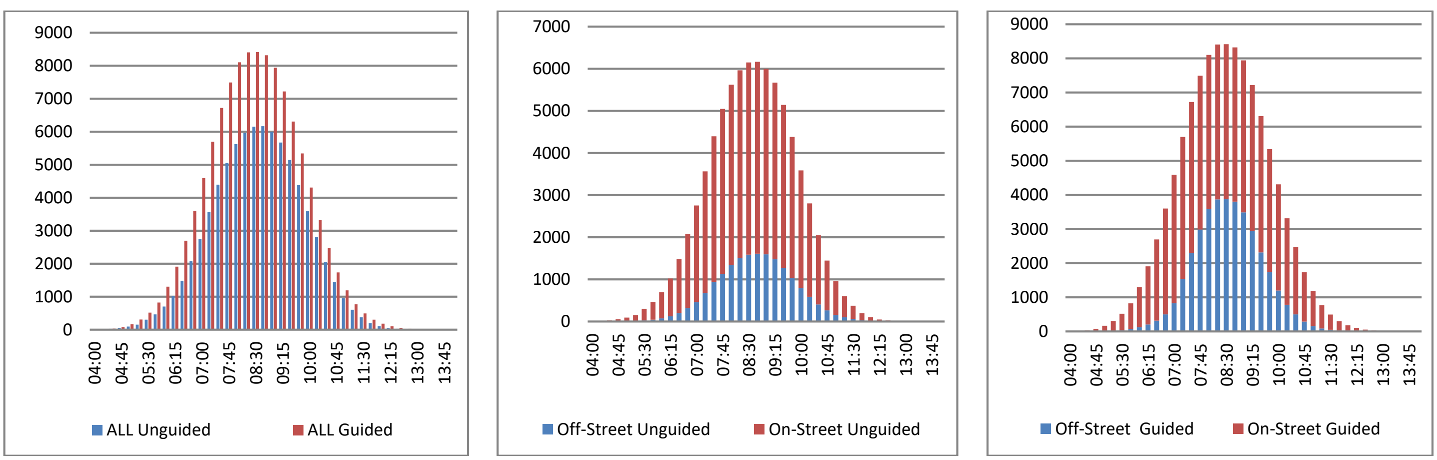


Figure 6. Number of vehicles at destination

The number of vehicles arriving at destinations is higher in guided environment than in unguided environment. This suggests that if conductors are guided to available parking spaces, the number of vehicles in circulation will decrease. Parking guidance reduces travel distances for drivers looking for available parking spaces and increases the number of vehicles arriving at their destination. Thus, traffic becomes more fluid. Furthermore, the vehicles on the unguided environment arrive at their destinations at 7:00 p.m. The guided vehicles on the guided environment arrive at their destinations at 16h. Thus, parking guidance systems can reduce three hours of road circulation.

B. Parking occupancy

For the unguided environment, the conductor cannot collect information about parking space availability. Thus, he is interested in finding the closest parking spaces to his destination. For the guided environment, the conductor is informed and guided to an available parking space. It optimizes the use of parking spaces.



a) Unguided vs. Guided b) Unguided c) Guided

Figure 7. Parking occupancy

Figure 7 illustrates the number of occupied parking spaces at different times of the day. It shows a comparison between parking occupancy in the two environments unguided and guided. The guided environment affects vehicles looking for parking spaces. Therefore, the parking occupancy rates are optimized to 28.38% (Figure 7.a). A comparison of figures 7.b and 7.c shows that guided environment is more efficient than unguided environment. The guided environment increases the occupancy rates for both on-street and off-street parking. These results also confirm the effectiveness of the parking guidance system.

C. Parking managers' turnover

At this level, we study the impact of guidance on parking managers' turnover.

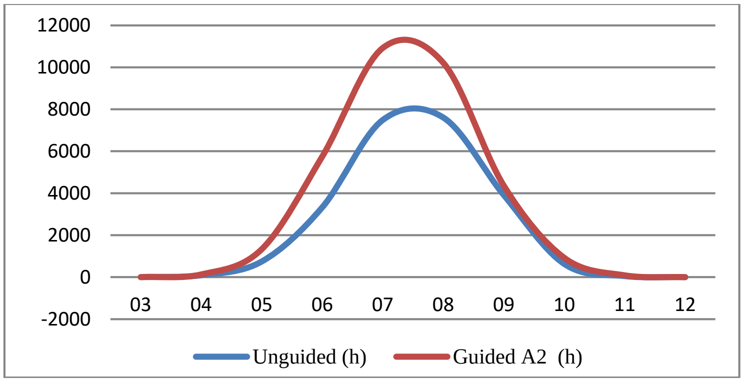
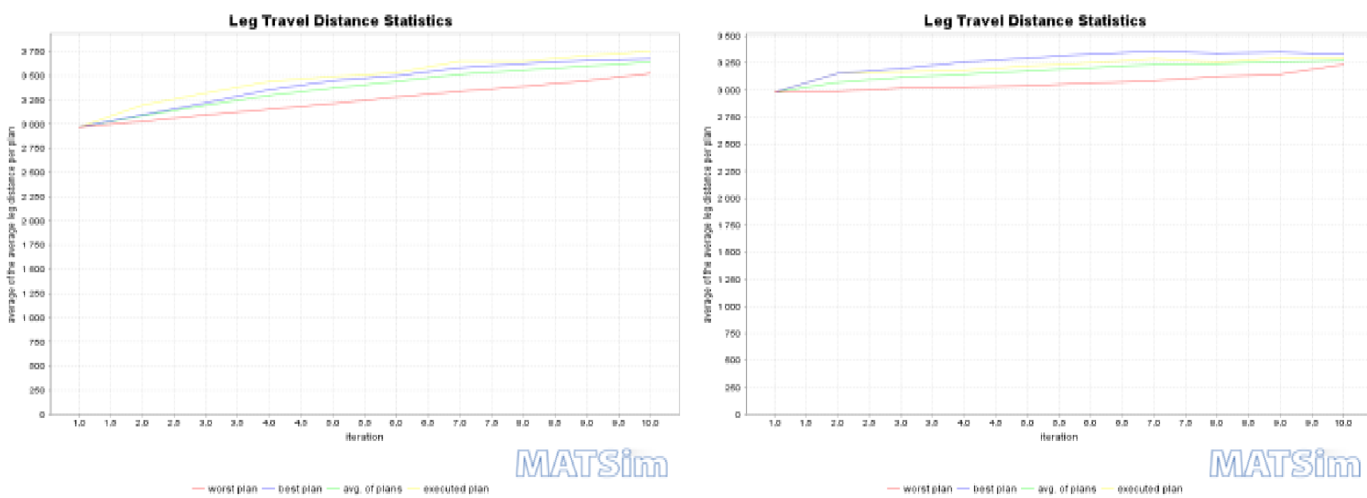


Figure 8. Parking managers' turnovers

Figure 8 illustrates the total turnover of parking spaces in each of the two environments (unguided and guided). Turnovers, especially during peak hours, is very high. It is due to the fact that the parking lots are close to being fully occupied. At the end of a simulation day, turnover is 33741 TND for guided environment, compared to 23857 TND for unguided environment. The turnover increased by 29.29%. Therefore, parking managers should apply the parking guidance system.

D. Travel distance

The travel distance is defined as the total distance traveled by a vehicle.



a) Unguided b) Guided

Figure 9. Travel distance

Figure 9 illustrates a significant reduction in travel distances. Travel distance is 3650km for unguided environment and 3200km for guided environment. Then, 450 kilometers are reduced. The results support the idea that parking guidance systems reduce traffic congestion.

E. Walking time

The figure 10 illustrates the walking time from the parking j to the final destination d.

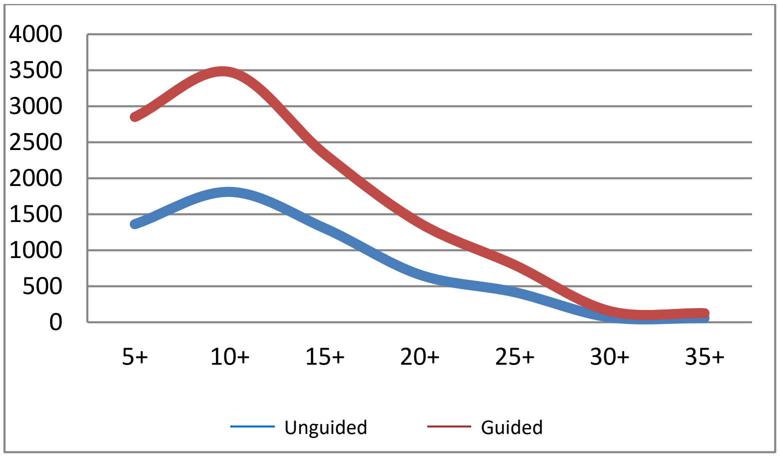
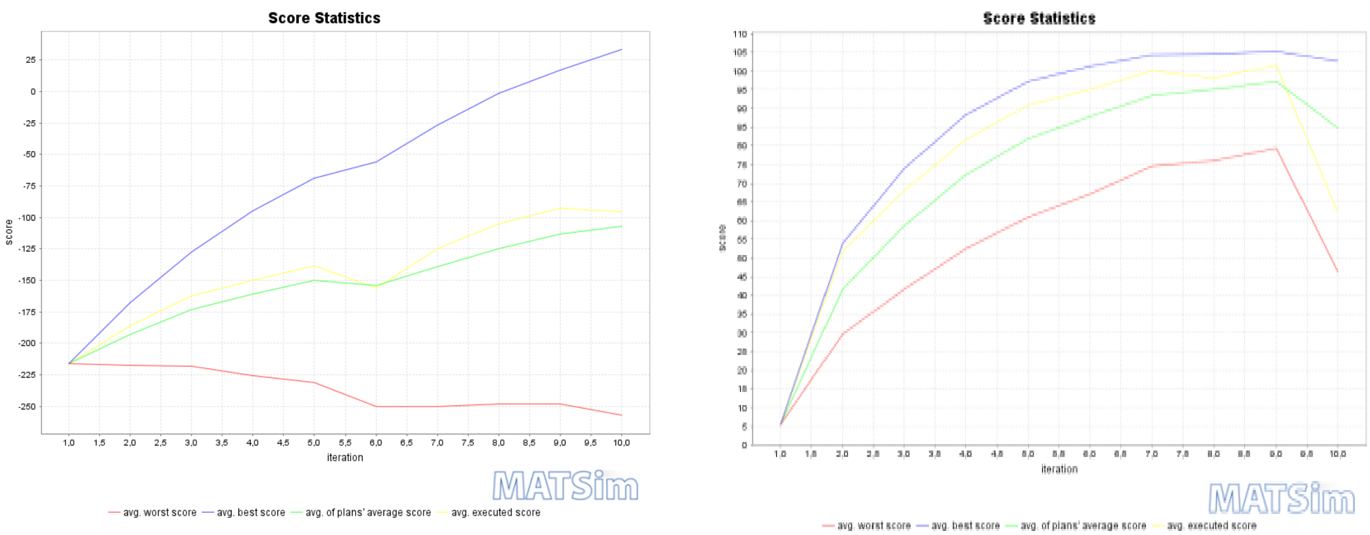


Figure 10. Walking time

The guided environment increases drivers' walking time compared to unguided environment. For guided environment, walking time is estimated at 13 minutes, while for unguided environment walking time is 12.14 minutes. An increase in walking time is related to the spatial dispersion of drivers in parking lots. The parking guidance system involves a sensible increase in walking time.

F. Social well-being

Social well-being is calculated as the sum of all the conductors' utility.



a) Unguided b) Guided

Figure 11. Social well-being

Figure 11 illustrates the social well-being change. It's lower for unguided environment than guided environment. The decrease is attributed to a reduction in parking search traffic, and travel distances. Even though walking time increased when guided environment was applied, smart parking guidance provided the lowest travel costs to drivers. The average social well-being of conductors is 25 for unguided environment and 103 for guided environment (iteration N° 10). As a conclusion, the guidance to available parking spaces maximizes the user's utility.

G. Environmental Cost

This section evaluates firstly the average saving of energy consumption and secondly the average carbon dioxide emissions.

G.1. Average saving of energy consumption

The transport sector in Tunisia is ranked second in energy consumption. It accounted for 34% of total energy consumption (The National Agency for Energy Conservation, 2010). The road transport sector represents 82% of the sector's consumption, followed by air, maritime, and railway transportation. A decrease in travel distance is accompanied by a decrease in energy consumption. Depending on the travel distance, the average saving of energy consumption can be calculated as follows:

$$ASEC = NV \times AFC \times TD \times APF$$

Where:

ASEC: Average Saving of Energy Consumption,
NV: number of vehicles,
AFC: average fuel consumption per 100 km (7 liters/100 km = 7%),
TD: travel distance,
APF: average price of fuel.

The table 1 shows the main differences between the two environments in terms of travel distance (total), and corresponding average saving of energy consumption. Guided environment is guaranteed to be more efficient than unguided environment. The average saving of energy consumption for the two environments is as follows:

$$ASEC = 20000 * 7\% * 3650 * 1820 = \ 46.501 * 10^8 \textit{ (unguided environment)}$$
$$ASEC = 20000 * 7\% * 3200 * 1820 = \ 40.768 * 10^8 \textit{ (guided environment)}$$

Reduction of travel distance (guided environment), including a reduction of $5.733*10^8$ in average saving of energy consumption, equivalent to a reduction of approximately 12.32%.

Table 1 Comparative statistics (1)

Environment	unguided	guided
Travel distance	3650 km	3200 km
Average saving of energy consumption	$46.501*10^8$	$40.768*10^8$

G.2. Average carbon dioxide emissions

Carbon dioxide (CO2) emissions represents one of the most detrimental effects of transportation on the environment. The official reports state that Tunisia's emissions of carbon dioxide have continued to rise (National Institute of Statistics, 2015). In Tunisia, 66% of cars are gasoline, 34% are diesel (The National Agency for Energy Conservation, 2010). In average, a vehicle consumes 7 liters per 100 kilometers. Knowing that one liter of diesel emits 2640g of CO2, diesel vehicle emits 184.8g of CO2 per kilometer (7×2640 /100), on average. In parallel one liter of gasoline emits 2392g of CO2, while a gasoline vehicle emits 167.44g of CO2/km (7×2392 / 100). Hence, we can calculate the average carbon dioxide emissions (ACDE), at period (t), by using the equation below:

$$ACDE = ACDE_{gasoline} + ADCE_{diesel}$$
$$ACDE = [NV_{gasoline} \times TD_{veh} \times 167.44] + [NV_{diesel} \times TD_{veh} \times 184.8]$$
$$ACDE = [(NV \times 66\%) \times (TD \div NV) \times 167.44] + [(NV \times 34\%) \times (TD \div NV) \times 184.8]$$

Where

$ACDE$: average carbon dioxide emissions
$ACDE_{gasoline}$: average carbon dioxide emissions for gasoline vehicle
$ACDE_{diesel}$: average carbon dioxide emissions for diesel vehicle
NV : number of vehicles
DP : travel distance
$NV_{gasoline}$: number of gasoline vehicle
$DP_{véh}$: average travel distance
NV_{diesel} : number of diesel vehicle

Table 2 Comparative statistics (2)

Environment	unguided	guided
Travel distance	3650 km	3200 km
average carbon dioxide emissions (g de CO2)	$63.2699*10^6$	$55.4695*10^6$

A diminution of the travel distance would reduce the quantity of CO2 emitted during the simulation. According to guided environment, the total quantity of carbon dioxide (CO2) has reduced by 12.32%.

IV. CONCLUSION

At present, Tunisia does not have a well-developed parking management system, and innovation is in its embryonic stages. Developing a smart parking system could lead to interesting practical results. In this paper, we propose a smart parking guidance system that can respond in real-time to the diverse requirements of drivers and parking managers. Multi-agent approach is used in this system.

Simulations were conducted on the road network of Tunis city-center. The numerical results illustrate the improvements that the parking guidance system is expected to bring, compared to a unguided driving environment. In addition, results were analyzed both from the perspective of the operator (parking manager) and from the perspective of the conductor (parking service consumer).

It is crucial to compare the simulation sorties for the two environments (unguided and guided). The smart parking guidance system mitigates traffic congestion by 15.51%, minimizes travel distance by 12.3%, reduces energy consumption and carbon dioxide emissions by 12.33%, increases revenue for parking managers by 29.29%, improves walking time by 5.32, and improves social well-being by 75.72.

In the following studies, an intelligent system based on dynamic parking pricing is an option that is worth exploring. If we have reliable sources for predicting parking occupancy, we could apply dynamic parking pricing to verify the parking demand for each parking facility, as well as the total travel demand in the road network. The dynamic price can be readjusted according to parking occupancy and demands.

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