Real-time Space Management
Andres Sevtsuk
The ubiquitous spread of real-time (RT) location-related information technology is enabling a reconfiguration of people’s daily urban commuting patterns. The situation presents designers with new opportunities to affect the behavior of urban systems (and with hazards as well). In particular, accurate information about the location of people and urban resources, and the availability of such information to individuals via handheld devices could allow a more efficient and sustainable allocation of urban resources. The urban systems affected are many, ranging from intelligent public transportation¹ and distribution of shareable city cars², to timely allocation and rental of urban places of assembly and real-time curb-parking information³. The latter is the focus of this study. An efficient allocation of urban resources, however, does not directly result from omnipresent access to real-time location information, but requires a fundamental understanding of urban planning to manage resources sustainably in complex situations. Studied in greater depth in operations research so far, the availability of real-time information about the city also opens up a new area of interest for urban designers: real-time space management.

The emergence of real-time space management can be viewed through three key processes unfolding in parallel.

First, the increase of the computational powers of handheld communication devices that provide information to individuals. This process is continuously improved by the manufacturer’s efforts to deliver increasingly powerful mobile phones to demanding clients.

Secondly, by the availability of location-related information from the environment and its distribution to people at an unprecedented extent and precision. This is achieved mainly through the monitoring of log files for communication networks, through individual tracking and a broad range of sensor data in the environment⁴.

Thirdly, by the development of algorithms that compute the precise kind and amount of information that can be queried by individuals in a personalized manner, depending on their location.

The first category – the technical progress of personal communication devices – is remarkably advanced by the private sector. The second and third categories – the collection of information from the environment and the development of algorithms to distribute the information most efficiently – are less likely to be seen in the private sector due to their lack of immediately visible gains for service providers. From an urban planning point of view, however, these two categories offer great potential for planners from the efficiency, congestion and simple scholarly standpoints of city design. In a well-functioning system the three components need to work seamlessly together. This is far from trivial, but possible indeed. Consider expanding the communication network of a well-functioning private firm to the scale of a whole city without compromising quality. The complexity of achieving this is not imposed by technical barriers of network size or capacity. Rather, the challenge is the efficient management of such a network through al-

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¹ See research in Mobility and Transportation in the 21st Century, Department of Civil Engineering, MIT. (http://cee.mit.edu/index.pl?id=4636)
² Concept Car Design. Smart Cities Group, MIT Media Laboratory. (http://cities.media.mit.edu/)
³ Service by Streetline Networks in San Francisco http://www.streetlinenetworks.com/index.html

Studied in greater depth in operations research so far, the availability of real-time information about the city also opens up a new area of interest for urban designers: real-time space management.
People are exceptionally good at perceiving and analyzing the physical environment, people’s sensory and analytical capacity in their physically close proximity is far greater than on any digital or mechanical system. However, this superiority is limited to a local context, generally within an individual’s visual field. The great advantage of modern computers is that they can efficiently analyze complex large-scale problems that involve numerous variables and information from different sources.

cheap proximity sensors on parking spots or through long-distance pattern-recognition cameras, processed and delivered to drivers via built-in navigation systems in cars or personal cellular phones and PDAs (Lee, Sevtsuk, Ratti, 2005). In the U.S., cars cruising for cheap parking constitute approximately 30 percent of all traffic in central business districts (Shoup, 2005). This causes excess traffic on streets and keeps zoning codes for parking from being reduced, even though neighborhood streets, and moreover off-street lots, do have parking spaces available at most times (Sevtsuk, 2006). An efficient real-time allocation system could reduce traffic, unnecessary pollution and fill the land designated for parking, which has gradually become

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Term used by Herbert Simon in Sciences of the Artificial 3rd Edition, 1996 MIT Press, to distinguish solutions that are not truly optimal, but satisfying to given constraints.
the single largest land-use in most Western cities, to its greatest capacity. This in turn, could provide an occasion to lower parking zoning codes and to construct smaller roads in contemporary cities.

Using an agent-based simulation model, I tested these assumptions with five gradually developed search strategies, where real-time information was used in different ways, and observed the resulting group efficiency from the model. The strategies were called Traditional; Intel_1; Intel_3; Intel_5 and Intel_7, where Traditional illustrated random search and the Intel strategies simulated guided searches. What I regarded as efficiency, was the minimization of the average search time for parking at a group level. Caused by variations in the type and amount of information fed to the agents, as well as alterations of environmental conditions, it appeared that different environmental conditions require different approaches for achieving efficiency. However, as illustrated by the comparison of efficiencies below, it became clear from the initial tests that the value of a real-time guidance system can be significant compared to a non-guided, random search. Even a small street grid offers a great amount of navigation combinations that drivers can pick before stumbling upon a street with a desired parking spot. On a 3x3 grid, guided searches resulted in approximately one-half the search time of a random search and on a 5x5 grid, about one-fourth.

The diagram further down exemplifies a comparison of the number of alternative travel paths on grids of different sizes, considering that cars can "wrap" out of the picture on one side and re-enter from the opposite side, creating an infinite torus-shaped topological continuum. The calculations show the approximate number (n) of different driving routes where no street segment is repeated and where the search continues until all possible paths have been exhausted. A simple 3x3 size urban grid with 9 intersections could offer a driver thousands of ways to miss the street where a vacant parking spot lies! Thus even in a small-scale urban grid the use of a RT guidance system could considerably decrease the overall searching times for street-parking. But how should the RT information about the availability of vacant spaces be used?

The most obvious solution seemed to make the information equally available to all searchers. Hence, every driver could observe the availabilities of vacant spaces on a screen or audio device and choose his most suitable parking option accordingly. This was tested in the Intel_1 strategy, where agents first acquired real-time information where vacant parking spaces lay, calculated which space was within the fastest reach and then started driving towards it. (Unfortunately I cannot give a detailed description of all models here, but interested readers can find them on-line.) In a 3x3 size urban grid, where demand and supply of parking were equal (6 spaces and 6 searchers), the strategy clearly improved group efficiency. The benefits were even more apparent in a larger, 5x5 size grid. In situations, where the number of searchers was much higher than parking supply (24 cars and 6 spaces), however, the efficiency was reversed, resulting in even longer search times than was achieved with a random search.

This deficiency in the over-demand situation was caused by the fact that if all drivers had equal access to the information, then several of them ended up driving towards the same space, which on the

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screen appeared closest to them all. Only the overall closest driver was actually able to park in the space while other drivers eventually found out that they had traveled in vain as the spot disappeared from their screens. In order to overcome this problem, reservations were introduced in the Intel_3 strategy. In Intel_3, agents again computed their nearest available parking space as seen from the RT list, but in addition, they also made a reservation to it. Once a spot had been reserved, it could only be occupied by the agent who had made the reservation and it was eliminated from the RT list that was reported to other drivers. The agent who made the reservation would then drive to the chosen space without altering its destination along the way. This seemed like an obviously beneficial strategy, which users in the real world would certainly appreciate. As the graph below indicates, under conditions where the demand and supply – the number of searchers and the number of spaces – were equal, reservations proved to be very efficient, requiring half the search time of the random search and also less than the previously discussed Intel_1 strategy. But when tested under more challenging circumstances, where there were many more searchers than parking spaces, reservations proved to cause severe problems. The resulting average search times turned out to be far greater than in the random search. Why?

As any agent could make a reservation to its closest available space on a first-come-first-serve basis, then reservations oftentimes happened to grant the space to agents who were much further away from the space than others who also desired to park in the same space. Thus the actual closer agents were

![Figure 2. Comparison of the number of alternative travel paths on different grid sizes. The calculations show the approximate number of different travel paths where no street segment is repeated and assuming that the search continues until all possible paths are exhausted.](image-url)
not allowed to occupy a reserved space that they passed and were instead forced to search at other, more distant locations. Even at the more distant locations, the same issue could occur again. Hence, the results showed that the first-come-first-serve reservations in situations of over-demand could cause severe deficiencies in the allocation process, resulting on average a 350% longer search process than in the random search. Despite the inefficiencies in Intel_3, I think that reservations would still be very useful in real life in order to serve special demands for people who need parking immediately, provided that such service was priced accordingly.

The low efficiency of the reservations policy at the group level rose from a poor management of the queue of simultaneously competing searchers. The issue of queuing is an example of how the introduction of digital control to the realm of physical urban systems can cause hazards that were either unimportant or non-existent in traditional urban systems. In traditional urban situations, queuing for spatial resources in simultaneous demand situations can be often absorbed by physical differences in travel times of the people making the demand. If B, C and D all want to use a particular resource at point A simultaneously, then queuing can possibly be avoided as it takes B, C, and D different times to reach point A. Considering that B, C and D all travel at approximately the same speeds, the order of allocation would naturally place the closest agent first and the furthest agent last.

However, in real-time communication, the time delay caused by physical distance changes, allowing simultaneous gatherings and demand to appear instantaneously. Hence, if B, C, and D had a real-time communication system to make appointments at point A, and their demands appeared again simultaneously, then a queue of their demands would have to be managed. The physical distances between the competitors and the spatial resource hence become crucial for the order of allocation. The parking simulation showed how simple individual reservations could jeopardize a parking situation if the system does not allocate spaces to the queue in a considerate way. Queuing is well known and studied in data systems and telephony where lines of bits and overuse of bandwidth often cause congestion, but the issue gains a new dimension in spatial systems, where the components that queue are actual people in physical spaces. Similarly to the street-parking illustration above, efficient queuing is necessary for the distribution of customized public transportation or shared personal vehicles, as well as other types of spatial allocation systems that use real-time communications. The use of digital communication for urban space allocation has to account for the physical efforts involved in relocating people and resources, as well as good queuing management. Unless carefully planned,

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Figure 3. A comparison of strategy performances between 6 and 24 cars on a 3x3 grid with 6 geographically dispersed parking spaces.

Figure 4. Absorption of physical queues in slow-interaction systems.

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Queuing Theory, the mathematical study of waiting lines, is well known in telecommunications.
an electronic system could cause severely wasteful allocation.

Queuing problems can be mitigated if participants of the system do not only obtain real-time information about the space or the resource they desire, but also about each other. Knowledge about the location and intentions of competitors for a particular resource can improve the overall performance of the allocation system as well as increase the benefits of individual participants. This requires a mutual sharing of personal location information. In order to avoid public display of sensitive information, the data can be used strictly for calculations within communication devices. Thus if the guidance devices of B, C and D in the illustration above had mutual knowledge of each other’s presence and intentions, then a considerate system algorithm could account for their positions and individually advise participants to use the resource at point A most efficiently according to the situation. In case a participant is unlikely to succeed in obtaining the desired resource immediately, then alternative resources at other locations can be offered.

The additional information about other participants in the system was added in the Intel_5 search strategy. Intel_5 attempted to unify the benefits of both Intel_1 and Intel_3, while avoiding their weaknesses. As in Intel_1, agents re-evaluated their destination from the real-time list of all available spaces at every step of the search. However, in order to avoid the occurrence of several agents driving towards the same space as in Intel_1, agents here did not use reservations, but instead mutual knowledge about the location of competing participants. Thus, when an agent consulted the real-time vacancy list, it did not directly choose the closest target space and start driving towards it, but also evaluated if any other agents had the same destination, and if so, how far they were from that destination. Only if the agent was closest to the target spot among all competitors, would it start driving towards the spot. If an agent was not the closest competitor to any spot, then it would search randomly for a moment and continue checking for guidance at the next step.

This evaluation procedure was repeated at every step. As mentioned above, in real life, the mutual information should only be used for calculation purposes within the communication system, and the optimal solutions of parking suggested to drivers on a screen. (Else we would end up with every driver trying to drive faster than others to reach a spot first!)

The strategy proved to work very well, in fact better than all other tested strategies under most circumstances. It confirmed that a mutual sharing of location information could allow a system to determine the optimal order of allocation and thereby considerably improve the efficient use of urban resources. In real-life applications queuing cars, which do not have an immediate allocation, could be allowed to use forbidden parking areas, such as fire-hydrant spaces, for temporary standing until the receive information about a vacating space in their vicinity. However, as an alternative to simple standing, the last Intel_7 search strategy was devised to enhance the search in conditions where no satisfactory solutions are readily available and one is forced to wait in a queue. In lieu of...
of waiting, Intel_7 introduced yet a new layer of information, which allowed agents to use probabilistic calculations to determine where vacant parking spaces would occur next. This could be achieved considering that the parking sensors on the ground also record the time durations of each occupancy of a spot, which allows the system to make intelligent guesses where and when vacancies might shortly appear, based on the statistics of parking duration and past experiences. The results of this simulation showed that Intel_7 performed better than Intel_5 only in the most challenging tested situation—on a 5x5 grid with 24 cars and 6 distributed parking spaces. However, the differences between the two models were not large and it is very likely that with a different initial position of agents, the advantages could reverse. In situations of low demand or small grid size, the performance differences of the two models are too small for clear conclusions.

Mutual location information sharing that led to efficient group performance does not merely allow individual guidance systems to make more optimized decisions in navigating a city, but also creates an opportunity for a deployment of new economic models, where competitiveness at the very individual level can be positively enhanced through collaboration with other participants. Collaboration of participants can be further incentivized by a dynamic pricing policy adjusted to maintain collaborative equilibriums using Game Theory. Accurate location information and performance monitoring could allow a system to precisely evaluate the impact of each participant and to adjust the value and incentives of used resources individually in real-time. Personalized pricing of public resources and dynamic adjustments of supply to demand are of course not unprecedented in economic markets, but the current spread of personal communication devices and accurate information from the environment allow such economic models to be deployed at unprecedented scale and precision. Competitive markets for real-time bidding of urban resources could in turn trigger a wider development of algorithms to aid individuals in locating their most efficient resources on the market. These algorithms are analogous to the existing digital avatars that automatically search the Internet for most profitable offers based on given parameters. If urban policy and guidelines incentivized mutual collaboration among the users of urban resources, similar tactics could be used in cities. Only through clear understanding and participation in the development of real-time information systems can the positive qualities of digitally enhanced urban systems be guided towards a more sustainable functional state.

References:
Lee, Sevtsuk, Ratti 2005, SmartStickers, paper submitted to the Microsoft Research.

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