Considerations for the Design of Automated Urban Transportation Systems

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ABSTRACT

The need for new transportation paradigms to address the problems associated with widespread dependence on personal automobiles appeared within a few decades of cars becoming available in large numbers, and has been growing ever since. These problems include traffic congestion, noise and air pollution, and the isolation of those without access to private vehicles. Throughout the years, researchers, policy makers, and private citizens have all looked to automated public transportation systems to create a cleaner, safer and more efficient way of life in urban areas. Despite their best efforts, this idyllic future remains frustratingly out of reach. This paper considers some of the issues associated with the design of automated urban transportation systems in an effort to understand the mistakes of the past and create more successful systems in the future.

INTRODUCTION

The first vision for an automated transportation system - taking the existing concept of a highway and automating it - was presented by General Motors at the 1939 World's Fair. The first concepts for Automated People Movers (APMs) and Personal Rapid Transit (PRT) systems began to appear in 1953, and Automatic Guided Vehicles (AGVs) for material transport in industrial settings were introduced in 1955 (Muller 1983). By the early 1960s, PRT-related publications began to appear, and by the late 1960s a series of studies sponsored by the US Urban Mass Transit Association concluded that non-conventional forms of transportation would be needed to mitigate congestion in the future. This led to 6 years of US federal funding for PRT-related research and numerous publications (Anderson 2005). Although PRT-related research dwindled after research funding became scarce, a “resurgence in research and development occurred during the 1990s” (Conttrell 2005), in part due to a large PRT project funded by the Northeastern Illinois Regional Transportation Authority. Interest in automated transportation systems continues today, now driven by global concerns about energy efficiency and environmental sustainability in addition to local efficiency and quality of life concerns.

Although automated urban transportation systems show great promise, successes have been limited and few. Today, there is only one Personal Rapid Transit system in operation (the Morgantown University PRT) and two under construction (one at London's Heathrow airport and the other in Masdar City in the United Arab Emirates). Governmental support, especially in the US, remains elusive. In 2007, a report prepared for the New Jersey Department of Transportation declared that “PRT systems are approaching but not yet ready for public deployment” and that while “[m]any of the technical components needed to support PRT systems are commercially available and are used in other industries...a fully operational PRT system is needed to demonstrate the theoretical benefits of PRT and establish commercial readiness” (Carnegie et al. 2007). In 2008, the Commonwealth of Virginia reached similar conclusions, stating that “While these advances have helped to demonstrate the feasibility of the technology, there are still many challenges that face PRT in terms of large scale deployment such as: technological limitations, a very small number of manufacturers worldwide, and proprietary system components that limit open competition and sustainability. Any application of PRT in the Commonwealth would likely require additional research, development and funding to ensure that the system is sustainable long enough to achieve a return on the investment” (Virginia 2008).
SCALE AND CONTEXT MATTER

Perhaps the first question to ask when discussing automated urban transportation systems is: why have past systems failed? But this question contains an assumption that past systems embodied the vision which is not necessarily true.

Proof of Concept Models for Urban Use Must Reflect the Urban Environment

Almost all automated transportation systems envision a future where users can travel comfortably, rapidly, and at their convenience to almost any location within a city without the need for a personal automobile. Unfortunately, almost all of the PRT systems that have been constructed have been limited to one or two fixed routes. For example, the Morgantown PRT, which has been operating continuously since 1975, contains a single line with 3.6 miles of track and 5 stations. The ULTra PRT system, which is expected to open at London’s Heathrow airport in late 2010, will initially consist of a single line with 1.2 miles of track, 21 vehicles and 2 stations (ULTra 2010). And the first phase of the Masdar PRT system is expected to consist of a single loop with 1.2 kilometers of track, 13 vehicles (10 passenger, 3 freight) and 5 stations (3 passenger, 2 freight. (2getthere 2010). These types of systems are well suited to walkable medium-sized environments with multiple buildings or attractions, a large numbers of visitors, and a small number of desired destinations like airports, university campuses, shopping malls, and amusement parks. However, these environments do not reflect the realities of urban living. Similarly, “[v]ehicle-based internal transport systems using automated guided vehicles (AGVs)” have been successfully used in a variety of facilities including “manufacturing plants, warehouses, distribution centers and transshipment terminals” (Le-Ahn and Koster 2006). However, these applications also have limited transit distances (usually intra-building or intra-yard) and a small number of high traffic delivery terminals. As a result, neither the existing PRT prototypes nor the success of AGVs in manufacturing can be accepted as proof of concept for operation in an urban environment from either the technical or social perspective.

Users Experience Must be Realistic to Obtain Meaningful Social Proof of Concept

In order to conduct meaningful user studies, users must undergo an experience that is as close to the real situation as possible. A study by Cook et al. (2004) showed that PRT users on a short test track gave a "strongly positive response to the system in essentially all respects” and argued that their results should be “regarded as strong evidence of the acceptability of PRT systems in general to the public as a whole.” However, Hine and Scott (2000) showed that “the costs associated with interchange [in public transport] both perceived and actual ... [including] time spent waiting, time spent transferring between vehicles and the attendant risk and inconvenience that are involved with this activity” were a major deterrent from public transit use in England. Although most automated urban transportation systems like the PRT are assumed to provide non-stop service to the users, the user must still travel to the station, wait for a vehicle, travel in the vehicle, and then walk to their final destination. If the PRT user studies take place under controlled conditions with no transit to and from the station, no luggage, no wait for a vehicle, no congestion within the network, etc., the study cannot be expected to uncover second-order problems or yield results that apply to real-world usage.

Prototype Scale Must Be Large Enough for Meaningful Technical Proof of Concept

The automated transportation systems that have been implemented to date have used full sized components (vehicles and guide ways) but have reflected an almost trivial state (single loop, minimal vehicles and stops, etc.) from a network perspective. Thus, they have been valuable in demonstrating technical proof of concept of the components. However, the complexity of a network (whether virtual or physical) scales non-linearly with size. In addition, the technical problems, especially those associated with the control of the system, similarly scale non-linearly with size. Thus, the existing prototypes have been unable to identify the unanticipated problems that will occur in large-scale networks or to prove that such a system could perform well on an urban scale.

System Scale Must be Large Enough to Realize Social Benefits

Like communication networks, the net usefulness of a transportation system is inherently linked to the size of the network and the number of connections that can be made to other locations or users. While the telegraph was a disruptive invention in its time, its impact on everyday society was not felt as acutely by the individual as were the changes that have been brought about by the ubiquitous personal cell phone. Similarly, the internet did not begin to reach its full disruptive potential until it was available for use by the general public. Transportation networks are no different; they must reach a critical size before they will be able to approach the functionality of personal automobiles and thus deliver the benefits in improved efficiency, safety, and convenience and reduced congestion and pollution that have been so widely anticipated. No existing system has even begun to approach the necessary level of scale and complexity.
Success Metrics Must Take Into Account Context of How Existing Technology Is Used

Futurists predicting the adoption of disruptive technologies frequently make the mistake of assuming that novel, superior technologies will provide a drop-in replacement for existing, less efficient or effective technologies. However, in general, this does not seem to be the case. Instead, new technologies often exist side-by-side with older ones for a long period of time before replacing them – if replacement occurs at all. This has been cited as one of the reasons for the overreach of early automated transportation visions, and the “failure” of implemented systems to realize these predictions (Geels and Smit 2000). Indeed, when we look at modern transportation systems, we do not see automation taking root at the levels predicted by GM in 1939.

But it could be argued that recent years have nevertheless seen widespread automation of ground vehicle networks. This automation has taken place within individual vehicles, rather than inside the network itself, in the form of in-car computation and satellite-assisted navigation systems. In some countries almost every car on the road has some form of computer-based mechanism for enhancing the decision-making skills of the (human) vehicle operator, through navigation assistance or traffic awareness. Because of its decentralized human-centric nature, the ground transportation network is resistant to top-down change, but highly susceptible to bottom-up adoption of technologies. In contrast, the air traffic control system has yet to incorporate GPS information in any meaningful way to improve system-wide efficiencies due to rigid top-down regulation. When these regulations are eventually altered, change will be rapid. In order to achieve progress in automating transportation networks, we must take into account the context in which technologies are used, and whether that context supports top-down, bottom-up, or parallel insertion of new technologies.

INNOVATION OFTEN COMES FROM THE FUZZY FRONT END

The design process can be thought of as having 4 basic steps: defining the problem to be solved, defining the design requirements that must be fulfilled in order to solve the problem, determining the best way to fulfill the design requirements, and doing the detailed engineering and design work to properly implement the chosen solution. The potential for innovation in each stage is limited by the decisions, assumptions, and constraints that were added in the previous steps. Thus, the greatest potential for innovation – and the greatest potential for failure – lies at the beginning of the design process in the so-called “fuzzy front end” (Belliveau et al. 2002).

Good Engineering Isn’t Enough

Unfortunately, much of the research and development of automated transportation systems has been done by transportation engineers and engineering designers who have focused their efforts on solving the difficult technical and operational questions associated with implementing these systems. Common research topics include the optimal number of vehicles and pick-up and delivery locations, vehicle scheduling, dispatching and routing, traffic management, idle vehicle distribution, battery management and failure management (Vis 2006). There are good reasons for this. The operational and engineering decisions that go into a large transportation system have an enormous effect on the cost and performance of the system. In addition, new technologies often go through a long incubation period where they must be “nurtured and further developed” by engineers to improve their performance characteristics before they are able to compete on the open market (Geels and Smit 2000). However, good engineering can only ensure that a given system functions properly and performs well. It cannot overcome any inherent flaws that the design concept might contain. Thus, good engineering is a necessary component of a successful design, but good engineering alone cannot guarantee success.

Need New Ideas, Not Just New Implementations

Many of the new design concepts in automated transportation that have been developed over the years have introduced new physical mechanisms to fulfill the design requirements associated with existing solutions, thereby creating new versions of old things. For example, systems which require a human driver and those equipped with a computerized control system have major physical differences. But the human and the computer perform the same functions: navigation, speed control, collision avoidance, etc. Similarly, tunnel based light rail systems and elevated monorail systems require different construction equipment, have different failure mechanisms, and provide a different user experience (one provides a view, the other does not.) But they are functionally equivalent: they transport people and/or goods through a system that runs parallel to the surface roads. Each physical mechanism has different advantages and disadvantages in terms of cost, performance, and usability. And a design concept that satisfies all of the design specifications is a necessary component of a successful design. But if there is a problem in the design specifications, or even in the definition of the original problem to be solved, the designers may find themselves with (another) correct solution to the wrong problem which has no greater chance of success than those that came before.
Human Centered Design is Key

The “fuzzy front end” refers to the earliest stage of design, in which the most serious design flaws are usually introduced. In this stage, problems and opportunities and potential stakeholders and their needs are identified, and design specifications are developed. The design tasks in this stage are loosely structured and the information that is available or can be collected is frequently qualitative in nature. Perhaps more importantly, the information being collected and analyzed is often based on complex, sometimes irrational, and ever-changing human preferences and behavior. So while these activities are extremely important and a major factor in the commercial success or failure of new products and systems (Moenaeart et al. 1995), they also introduce problems which often do not appear or are not understood until after a product has failed in the market place.

The role of humans and the impact of their choices on the success or failure of transportation paradigms cannot be emphasized enough. Nor should the difficulty of accounting for the human element be underestimated. For example, it is well known that information provided by participants in user studies often does not match their observed behavior. Participants in an ULTra PRT study “suggested that passengers [were] prepared to accept higher fare levels than buses for the trip” (Cook et al. 2004). But this statement has little meaning when we consider the fact that public transportation users in England chose taxis over the bus (even when the bus was free) when factors including weather, location of bus stops, and the bus schedule were unsatisfactory (Hine and Scott 2000). In addition, it is well known that costs affect decisions differently when paid in advance, at the time of service, or at the end of the month or year. Thus, systems that allow users to pay roadway tolls automatically without stopping can greatly reduce the disincentive to travel on a toll road or to use private transportation.

CONCLUSIONS

There are many issues that influence the success of automated urban transportation systems. This work has addressed some of the issues associated with scale, context, the design process, and the complexities introduced by the users of automated urban transportation systems in an effort to understand the mistakes of the past and create more successful systems in the future.

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