PERSONAL RAPID TRANSIT

The unrealized potential of Personal Rapid Transit

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Personal Rapid Transit can be a game-changing concept for private transport in congested urban environments with high costs of vehicle ownership. Practical automated vehicle technology and efficiency gains will outweigh the inertia for PRT adoption.

A personal driver-less vehicle, along with the flying car and lunar cities (Milo 2009), is one of the concepts that failed to be delivered on time from the optimistic prognostications of the 1950s and 1960s. While that future is yet to come, the technologies for the eventual deployment of personal rapid transit (PRT) are being advanced. In this article I review the vision, the current status of PRT systems and related technologies and examine the potential, the advantages and the disadvantages of such systems for urban transport.

The vision

The defining characteristic of a PRT system is a small-sized driverless vehicle that operates on demand (The requirement adopted by the Advanced Transit Association for separated right of way is too restrictive.) A PRT system aspires to combine the on-demand and private space advantages of a personal car with the convenience and efficiency of a transit system. PRT operating models can span the spectrum from a purely public system with stations, to car sharing pods (a zipcar with no driver that picks you up at your door through prior arrangement and delivers you at your destination) to privately owned automatic cars. The PRT vehicles operate at the same level of separation as roads and trams from pedestrians and non-motorized traffic.

While in operation all-electric PRT vehicles can create virtual trains by "tailgating" with very short headways at distances of half a meter or less, moving at high speeds while using narrow lanes. A PRT system requires no traffic signals visible or otherwise, yet congestion is a virtual unknown and throughput is close to the maximum of the free flowing traffic. When stopped, their batteries act dependably as a grid stability mechanism and their owners are compensated accordingly.

The bits and pieces

Reaching anywhere close to that vision requires impeccable communications and optimization algorithms as much as transportation hardware.

For the physical infrastructure, a PRT system does not really require significant investment if it can utilize the existing road infrastructure. One thing that is *sine qua non* is very accurate positioning, which can be achieved by a combination of satellite positioning, on-board measurement devices and roadside markers. The vehicles themselves need to have a suite of vicinity-sensing equipment, i.e. radars, that create the awareness bubble of the vehicle effectively leaving no blind spots.

On the software side, things become more complicated. For a large-scale system implementation, as opposed to individual robotic vehicles, seamless coordination between vehicle control and transport-system operations is an absolute requirement. Without such coordination, the system performance cannot achieve the efficiency improvements that would make it worthwhile nor reach the very high safety and reliability standards that would be required for widespread adoption. This requirement for communication implies high computational power both on the vehicle and on the control system.

There are three schools of thought on how the PRT system operations would be organized: centralized (synchronous), distributed (asynchronous), and hybrid. Centralized systems operate with minimal intelligence on the vehicle aside from obstacle detection and guidance control. All vehicle operations, including navigation, junction negotiation, and scheduling, are performed centrally. This creates the need for the central system to have rapid, real-time updates of the system status and the ability to compute and direct the optimal trajectories for perhaps thousands of vehicles. Distributed systems, on the other hand,

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are bottom-up relying on peer-to-peer communication and priority negotiation based on preset rules akin to the proposals for future generation air-traffic control system. Distributed intelligence eliminates the need of the central system making operations robust and self-organizing. Intuitively, the hybrid systems fall in between, allowing for low-level functions to be performed locally (thus removing the requirement for high-bandwidth real-time communications to the central system – updates over the span of a minute with higher level information would be sufficient) but at the same time allowing for system-wide optimization; thus, they seem to be the more likely systems for widespread adoption although there is a debate on their relative merit [cf. (Fernandes and Nunes 2010), (Anderson 1996)].

Advantages

The potential advantages of a PRT system can be categorized into efficiency, safety, and convenience.

Efficiency

The main thrust of efficiency improvements are achieved through system-wide coordination, i.e. the primary efficiency gains come from the system operations. Firstly, there is the ability to create virtual vehicle trains where the air drag is reduced substantially for the following vehicles, a feature that can be useful for urban high-speed motorways.

Yet, more important is the ability to optimize intersection and on-ramp behavior negating the need for stopping and the energy and trip time inefficiencies associated with it. Additionally, congestion, the very costly in time and energy transportation system behavior emergent from the interaction of overreacting human operators, can be mitigated. PRT systems reduce incident occurrence that is a trigger for congestion and, as all vehicle trajectory vectors are known, it can redirect or slow vehicles to match free-flowing traffic conditions in the instances where demand still exceeds available capacity. Finally, as vehicles operate on demand, there is efficiency potential from the increased load factor, especially if a car-pooling function is enabled. This potential, though, is counterbalanced by the need to potentially reshuffle the empty vehicles to match peak demand.

On the vehicle side, accident probability reduction can allow the vehicles to become lighter again by value engineering some of the heavier passive safety features. Moreover, in a car-sharing PRT system, the equipment utilization – the amount of time that the vehicles are used – is much greater than in the case of private cars.

Safety

The assumption of safety relies on system design. Theoretically, the continuous vigilance of PRT vehicles would eliminate the major cause of accidents, which is the human factor alone (57%) or in combination with vehicle and roadway factors (37%) (Lum and Reagan 1995) (Rumar 1983). Driver aggression, inattention or impairment (e.g. speeding, running red light, texting and talking on the phone, driving under the influence, etc.) would become irrelevant. Of course it is possible that other factors due to system complexity could induce new failure modes (cf. Pitfalls section), but as long as the vehicles are equipped with multi-level safety systems that can operate passively, there are ways to address these concerns.

Convenience

The single most attractive feature of the PRT systems for the user is their convenience. Travelers can expect to minimize trip time due to the door-to-door congestion-free ride. Moreover, they can expect to utilize the actual travel time to their benefit – communicating or working without worrying about operating the vehicle.

Pitfalls

Technology dreams, especially those that require massive transitions, can be transformed into impossibilities or nightmares depending on the confluence of economic, technical, and social factors which are discussed in some more detail below.

Economics

PRT systems today can be expensive (cf. Masdar section) but this is true for any prototype system. The question is whether initial adopters can capture the advantages outlined above in a way that provides sufficient recouping of the investment that will allow widespread adoption and volumes to make learning and scale economies possible.

Complexity and Catastrophic Failures

The failure modes of complex, tightly coupled systems can be surprising and inherently lie in the design of those systems (Perrow 1984). Therefore, an important disadvantage of a PRT system would be these potentially unpredictable failure modes due to its complexity. The same can be said for the Internet. Unlike the Internet, which is massively parallel and does not control physically thousands of people moving at homicidal speeds, a PRT system can fail spectacularly with catastrophic consequences. Such an event, although highly unlikely, cannot be ruled out but at least can be engineered against massive death tolls,

though not necessarily against massive gridlock. In principle, the decoupling and subsidiarity provided by hybrid and distributed PRT systems would make them less susceptible but not immune to these types of failures.

A further complication stemming from the probability of failure is the regulatory handling of liability in that case. Until safety systems are proven, other features like the very short headways and traffic integration will probably not be permitted for commercial operations.

Acceptance and Control
Even a perfectly functional system can be hindered if its users do not accept it. The primary area of user concern would be related to the feeling of lack of control and associated safety concerns but also to the fun and prestige factor of driving a vehicle. The statistical misconception that leads the vast majority of drivers to claim that they are better than average would be active in this case. Even a minor incident, could be magnified. Yet, actual practice shows that people accept to be driven by other human drivers, ride in mass transit and even driverless vehicles without much apprehension.

Other aspects of lack of control are probably going to be more of a concern in the longer term: namely privacy, potential for malicious attack and hacking, and higher government control over transport. Privacy issues relate to the fact that identifiable travel information about the user of a PRT vehicle can be collected. Most users of a phone have already surrendered the privacy of their calls and a functioning democratic government can place enough oversight to mandate anonymization, thus facilitating acceptance. Yet, this same controllability and IT-reliance makes the PRT system a prime target for malicious hacking attacks, given its potential for high-visibility disruption. And for those less willing to assume benevolence on the part of the government, the fact that all vehicle operations can be directed centrally could mean that it can become a tool in the hand of government for impeding civic

demonstrations by freezing transportation towards a particular location.

The Jevons' Paradox of Mobility
Interestingly, one of the adverse effects of a PRT system could come from its success. Jevons observed in the early 19th century that when the efficiency of processes utilizing coal increased, coal consumption – counter-intuitively at first glance – also increased (cf. (Alcott 2005) for an overview). The phenomenon, also known as induced demand or rebound effect, is by now well established and can apply to transport. As the travel time budget has remained remarkably consistent across centuries (Schafer and Victor 2000), travelers tend to use the extra speed of travel to increase the distance traveled. Similarly, PRT's convenience and time efficiency, by allowing travelers to reduce their perceived trip time and expenses, can induce users to opt not only to increase travel with a private PRT compared to a private car but also shift travel away from traditional mass transit if the price and availability of PRT systems are right.

Current incarnations
The discussions above may sound premature, but the reality is that PRT systems have started to transition from ideas to materiality. The honorable mention has to go to the first and oldest operating transit system called a PRT: located in Morgantown, West Virginia, it is operating like a small on-demand rail line and has gained appreciation for its convenience (Hamill 2007). Yet, three more recent and ambitious cases of implementation are: Rotterdam Port, Masdar City, and the Google Car. Other notable developments include the Heathrow Airport PRT and the newly announced GM EN-V prototype.

Rotterdam Port
The automated guided vehicles (AGVs) that operate the container transport at Rotterdam port are not technically

Figure 1 | Current incarnations of PRT-related systems: (A): Automated guided vehicles in port of Rotterdam, B: Masdar City PRT, (C): Google Car (Sources: http://www.gottwald.com/, http://www.2getthere.eu/, http://www.nytimes.com/imagepages/2010/10/10/us/10google2.html)

a PRT but they provide a good illustration of a complex, multi-vehicle automatic system operating efficiently and profitably (Figure 1A).

Masdar City

The Masdar City is a futuristic and ambitious development of an eco-city in the heart of the desert, near Abu Dhabi's airport. Although scaled back in the past few years, it intends to be a zero-carbon renewable energy industrial cluster with mixed use of R&D, university, commercial space and residencies. The master plan originally conceived by Foster and Partners called for a carless development relying on an all-electric PRT network system that would operate below street level and serve both passenger and freight needs. The first phase of the system is in operation (see Figure 1B) developed by 2getthere and comprises of a single loop carrying from 700 to 900 pax/day and reaching a peak of 3600.

The prototype nature of the system meant that vehicle and infrastructure costs were comparatively high while reliability is less than ideal. This and the rescaling of the development project are probable reasons that led Masdar City to consider more traditional alternatives. Yet the system design was shown to be generally adequate, with some modifications (primarily the inclusion of larger group rapid transit GRT vehicles) for large scale adoption (Mueller and Sgouridis 2011).

Google car

The automatic driverless car is actually driving itself in the United States. Spurred to its development by a DARPA challenge, and not strictly a PRT, it demonstrates that current technology allows automatic vehicles to negotiate normal road traffic conditions (Markoff 2010) (Figure 1C).

Concluding Thoughts: The Transition Forward

With the harnessing of abundant and deceptively cheap fossil fuels, the speed of mobility increased so much that allowed the average middle class citizen of developed countries to create personal and business networks that span hundreds and often thousands of kilometers. Mobility is essentially considered a right synonymous to freedom. As energy becomes constrained to renewable and low-carbon fluxes, mobility will remain high on our agenda. PRT systems with their promise of efficient operations can offer a valuable mobility tool.

The PRT system future likely does not lie with individual traffic-restricted applications nor with traffic-integrated automatic vehicles; these prototypes may help propel the concept and implementation but are not likely to

be viable primarily due to their cost and restricted potential for scale economies for the former and regulatory nightmares for the latter. Rather, the transition will probably come from the merger of the automatic car with the PRT concept at cities like London or Singapore, where the cost of private vehicle operations is already high and the desire for a low-carbon transport system is strong. An area for PRT vehicle operations can be associated with the city center. There, shared PRT vehicles could be made available to complement the public transit modes. Private cars that would like to enter the PRT-zone would be allowed to do so with the requirement to have installed (or retrofitted) a PRT-compatibility kit. As technology gains in reliability and proves its operational efficiency, the regulatory system (along with the insurance industry) will start favoring automatic vehicle operations over conventional driver-based systems.

It takes time and effort for a paradigm transition, but when its time comes it can be pretty rapid indeed… ★

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