New Patterns in Urban Planning for Car-Free Development

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Abstract

A rationale is offered for deploying Automated Transit Networks in new developments before existing cities. Designs are explored for ATN stations that are capable of being very closely spaced. Guideway layouts for one- and two-level networks are examined. A preliminary layout is presented for a hypothetical development that has the potential to provide high mobility and quality of life without the need for automobiles. Finally, some implications of this study for the design of ATN technology are examined.

Cities everywhere face a number of transportation-related challenges including traffic jams, crashes, poor air quality, and inadequate parking. Automated Transit Networks (ATNs) have been developed as a means of addressing these and other problems. An ATN uses small vehicles that are routed over a network of overhead guideways by computer control.

So far, most discussions of ATN implementation have focused on retrofitting them into existing cities. Finding ways to shoehorn an ATN into an environment that was designed for the automobile – or the horse and buggy – is an important challenge that deserves further study, but it may not be the best place to begin. There are several inherent disadvantages and complications involved in introducing ATNs into existing developments:

- Large scale construction projects in occupied areas require elaborate construction barriers. And to avoid obstructing traffic, much construction work must be done at night using artificial light.
- Most projects will require some relocation of existing utility lines, signage, and lighting, as well as alterations to landscaping.
- The need to route guideways within established public rights-of-way, and clear of existing buildings, can result in a network layout that is less efficient and more expensive.
- The cost of building a second alternate transportation system is generally viewed as an expensive and unnecessary luxury.
- People who make their living building, maintaining, or operating the existing transportation modes will be understandably concerned that their livelihood could be undermined.
- People are naturally reluctant to alter familiar surroundings and habits.

These impediments, and others, can be avoided by introducing ATNs in new purpose-built developments. If ATN stations are conveniently located throughout the development, then it becomes possible to omit nearly all ground-level motor vehicle traffic, providing many additional benefits:

- Less asphalt, more green space. Most parking lots, driveways, garages, filling stations, traffic signals and signs, etc. can be eliminated.
- A safer and more pleasant environment for walking and cycling.
- Less noise.
- Better air quality.
- Lighting, signage, fire hydrants, utility lines, etc. can be integrated into guideways to reduce clutter and cost.
- Guideways and stations can be integrated into building.
- The development can be a draw to those seeking a car-free lifestyle, without disrupting the lives of others.

In the U.S., in the 1990s, over 60% of new houses were built on previously undeveloped land.[1] So there are lots of opportunities to try out new ideas in new developments, as well as in redevelopment of brownfields or of areas that have been destroyed by natural disasters.

A Hypothetical Design

Environmental Design is the intersection of architecture, landscape architecture, urban planning, transportation planning, and natural resource management – everything that contributes to our experience of a place. To be successful, it must be responsive to every aspect of its situation, including hills, valleys, rivers, lakes, drainage patterns, climate, economy, culture, and history. But that does not mean that new concepts cannot be explored independent of a particular site. In fact, by setting aside the features of a specific location, it is ofter easier to see fundamental underlying design principals.

Some preliminary design work may enable people to visualize what car-free developments might look like, and how they will work. This may help to start a dialog about new possibilities for car-free living. In addition, the lessons learned from deploying ATNs in new developments will be of interest to existing cities as they gradually come to rely on ATNs to meet their transportation needs.

Finally, creativity is often enhanced by postponing the consideration of certain limitations until later in the design process. This allows us to focus first on *what* we want to do, and only later on *how* to do it. Once we have a tangible vision of our goal, we may find surprising new ways to make it a reality. And so in this study, we start with a blank slate, assuming a flat and featureless landscape with an average climate. But even though we are designing for an imaginary site, the designs themselves must be firmly rooted in financial and engineering reality.

[1] United Stated Department of Agricultural, http://www.nrs.fs.fed.us/urban/, retrieved 1/2/2015.

Design Objectives

At first glance, it may seem that what we are talking about is Transit Oriented Development (TOD). But TOD was developed around the characteristics of so-called "light rail"[2] which can move lots of people between a small number of large, widely-spaced stations arranged along a linear route. This means that each station must serve a large area. But since most people will only walk to a transit stop if it is nearby, stations must be surrounded by high density development in order to generate enough demand to "justify" the large trains and large stations.

The design methodology proposed here is in a sense the exact opposite of TOD. We begin with the needs of people, and design everything around them. The reason people come together in cities in the first place is to have ready access to a wide variety of other people, opportunities, and resources. This is why mobility is at the heart of urban planning. And so, our overriding goal is to enable everyone to go anywhere quickly, safely, and economically.

We also want transportation to be so simple and predictable that people never have to think about it. This too is the reverse of the current trend toward congestion pricing as a means of "raising consciousness" to discourage travel at peak times or in congested areas.

Most people want to live on a quiet and safe street, which means a street without much motor vehicle traffic. This is especially important to people who have children. Adults will put up with a lot, but the truth is, an environment that isn't good for children isn't good for anyone. So we want to eliminate as much ground-level traffic as possible.

ATNs can get people to their destination faster than cars even while traveling at a lower speed. This is because ATN vehicles, or *pods*, almost never need to stop at intersections. Nevertheless, people have grown accustomed to traveling on surface streets at 35 to 45 miles per hour (~55 to 70 kilometers per hour), and are likely to regard anything slower as inferior. So we believe that our ATN must operate in that speed range to be viewed as a viable alternative to the automobile.

Convenient access to transit stations is another vital factor in broadening the appeal of public transit. Table 1 give some idea of how long it takes to walk to stations at various distances.

Walk Time (minutes)	**Distance**		
	(feet)	(miles)	(meters)
3	880	0.166	268
4	1173	0.222	358
5	1466	0.277	447

Table 1 Distance traveled at a typical walking speed of 18 minutes per mile.

[2] "Light Rail" is a somewhat misleading name because light rail trains, formerly known as street cars, are actually quite heavy.

These figures assume that you can walk in a straight line to a station. In practice, the path to a station will not always be so direct, perhaps increasing the walk time by up to 50%. To keep the maximum walk time well under five minutes, we will use a maximum walk distance of 1/6 mile (880 feet or ~268 meters). It is not uncommon for motorists to walk further than that to the nearest parking space. This corresponds to a station spacing (which we refer to as *d*) of 1/3 mile (1,760 feet or ~536 meters), and a catchment area for each station of ~2,682,600 square feet or ~61.58 acres.

We can represent the area served by a station as as circle of diameter *d*. If we want every place to be within d/2 of a station, the best way to arrange those circles is in a hexagonal or honeycomb configuration as seen in Figure 1. To put this in perspective, let's compare it to a state-of-the-art conventional public transit system consisting of a light rail line and a system of feeder/distributer

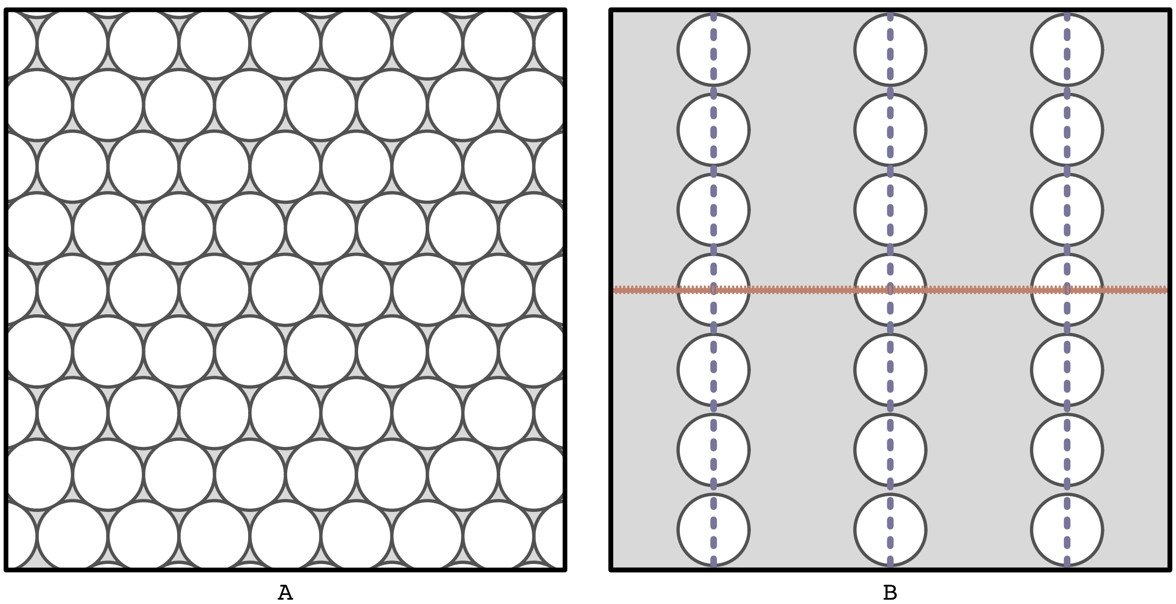

Figure 1 – Transit accessibility for ATN (A) and light rail/bus (B).

Figure 2 – Mathematical properties of the honeycomb.

buses. The average station spacing for the ten largest (by passenger traffic) light rail systems in the U.S.[3] is about 0.83 miles. The spacing between bus stops varies widely, but 3/8 mile is generally considered very good. This is depicted at the same scale in Figure 1. The shaded portion is the area that is beyond a five minute walk, and thus effectively unserved by transit. The challenge is to find a practical way to connect stations in this high-density hexagonal arrangement. For reference, Figure 2 labels a few of the mathematical properties of this configuration.

Many ATN systems use guide rails to guide pods through intersections. In these systems, each pod has a computer-controlled mechanism, called a *switch*, that can engage either the left or right

[3] Source: Wikipedia, "List of United States light rail systems by ridership", accessed 10-5-13.

side of the guideway. As a pod travels over the network, there is a sequence of events that mst take place between switch points. It must 1) verify that it has passed the previous switch point, 2) throw the switch, and 3) verify that the switch is properly engaged. At that point, there still must be enough time left for the pod to come to a safe, controlled stop if a problem is detected. In a dense network, traveling at the speeds we are envisioning, there isn't a lot of time between switch points, and it take longer to come to a stop, so we want to maximize the distance between switch points.

And so to summarize, these are our design objectives:

- Walking and cycling should be safe and pleasant.
- Car-free living should be possible.
- The entire community should be served by public transit, so no place should be more than 1/6 mile from a transit stop.
- The operating speed should be comparable to the automobile.
- The turn radius should be as large as possible.
- The distance between switch points should be as large as possible.
- Full cruising speed should be maintained on the main guideways and turns. No slowing down before exiting onto a siding.

Station Design

When stations are close together, each one serves a relatively small area. So most stations will not need to accommodate high demand. What we need is just the opposite – the ability to economically handle a very light passenger flow. In fact, at the periphery of the network where there is no through traffic, it is even possible to use in-line stations. These can be thought of as extra-long sidings that extend the reach of the network.

The most straightforward way to link a row of stations is to run a main guideway parallel to them with parallel off-line stations as depicted on the left of Figure 3. But when stations are close together there isn't enough space to accommodate the acceleration segment, the deceleration segment, and the minimum distance between switch points. One possible solution for this problem is the *Overlap Station* depicted on the right of Figure 3. In this station, the debarking platform is placed at the end of the siding, and the boarding platform at the beginning. When a pod enters the siding, it has the entire length of the siding to come to a stop at the debarking platform. Once passengers have exited, it backs up at low speed to the boarding platform, from which it has the entire length of the siding to accelerate before merging back onto the main guideway. Alternately, a single boarding/de-boarding platform can be placed anywhere along the siding, and accessed by the pod as it backs up from the end of the siding to the beginning.

The Parallel Station and the Overlap Station share a disadvantage. Their sidings each have an S-turn just as they enter or leave the main guideway – when the pod is traveling at near line speed. For the passenger this means a sharp lateral jerk first to one side, and then the other. We can improve ride comfort, and at the same time increase the minimum distance between switch points by using a *Perpendicular Station* as illustrated in Figure 4.

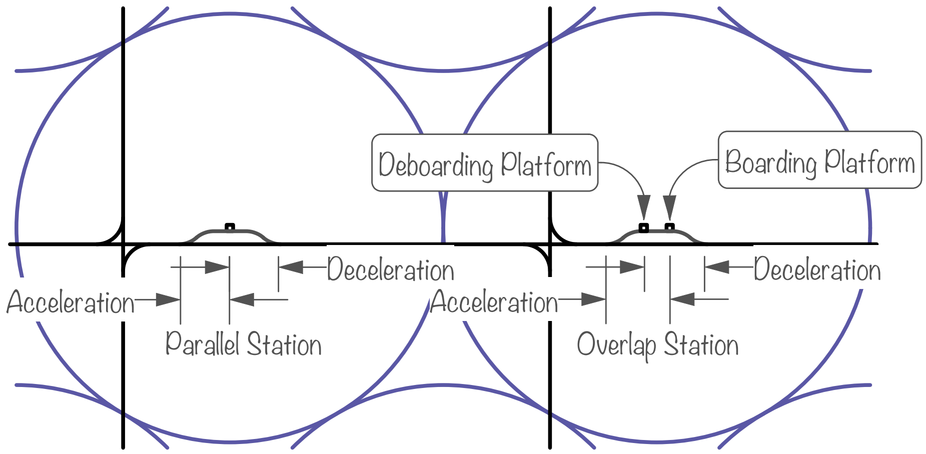

Figure 3 – The Parallel and the Overlap Stations

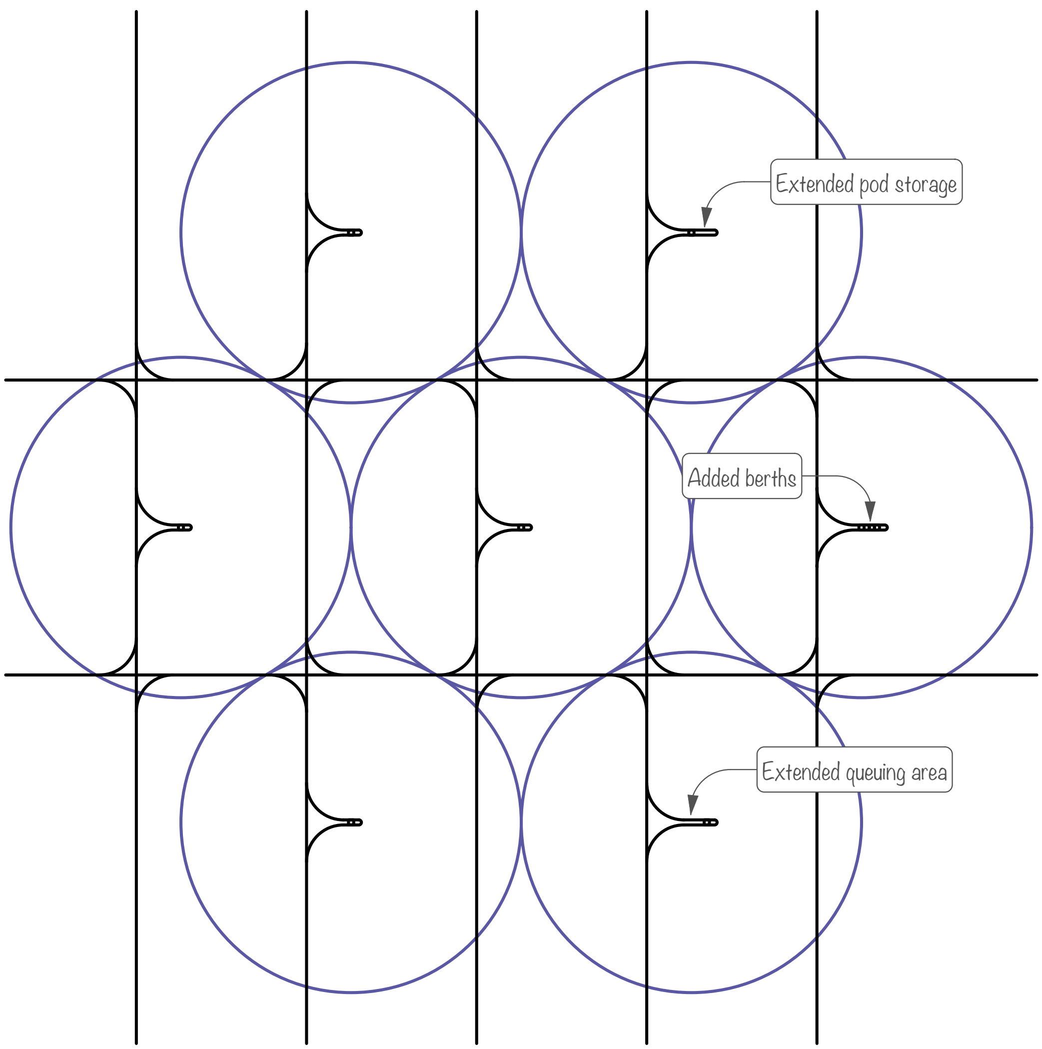

Figure 4 – The Perpendicular Station

This station has the potential to be relatively compact and inexpensive because the embarkation and debarkation platform doors are on opposite side of a small platform. This also eliminates the problem of boarding passengers crowding around the vehicle door, preventing debarking passengers from exiting. As pods travel from one side of the platform to the other, there is a short segment of guideway in which unoccupied pods turn around. This turn-around area does double duty as a place to store empty pods, which means that when an occupied pod enters a station it is not necessary for an empty pod to depart unless the buffer area is already full. It is relatively easy to expand the capacity of this station, even after initial construction, to add more births, more empty-pod storage, or larger inbound and outbound queuing areas as illustrated on the right side of Figure 4.

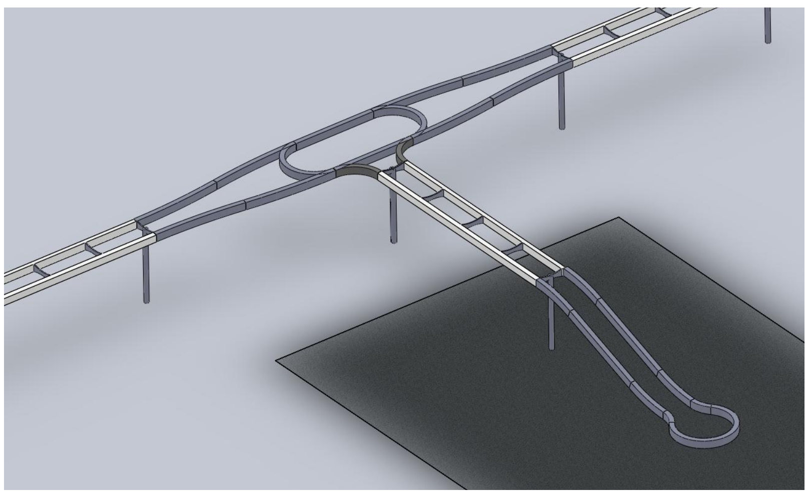

Figure 5 – Perpendicular Station with guideway descending to ground level
Courtesy of Beamways, AB. Used with permission.

Single Level Guideway Patterns

In an ATN, all the guideways can be on a single level or on multiple levels. In single-level configurations, guideways cannot cross, so networks are typically composed of intersecting or interconnected loops (Figures 6 and 7 respectively). Note that two intersecting loops must have opposite directions of flow: clockwise or counterclockwise. As a result, you cannot have three (or any odd number) of mutually intersecting loops.

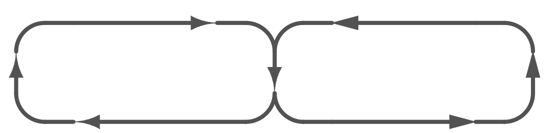

Figure 6 – Network of intersecting loops.

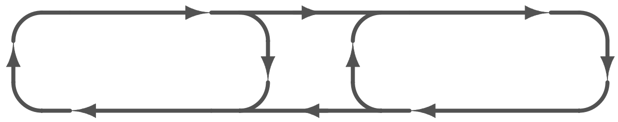

Figure 7 – Network of interconnected loops.

These patterns can work well for small networks, but in a more extensive configuration, as depicted in Figure 8, travel in one direction is straightforward and direct, but in the orthogonal direction the path is quite circuitous. This pattern may be well suited to a community that is long and narrow, such as might be found in the bottom of a river valley. In other situations we might do better with a configuration that removes any bias in the direction of travel.

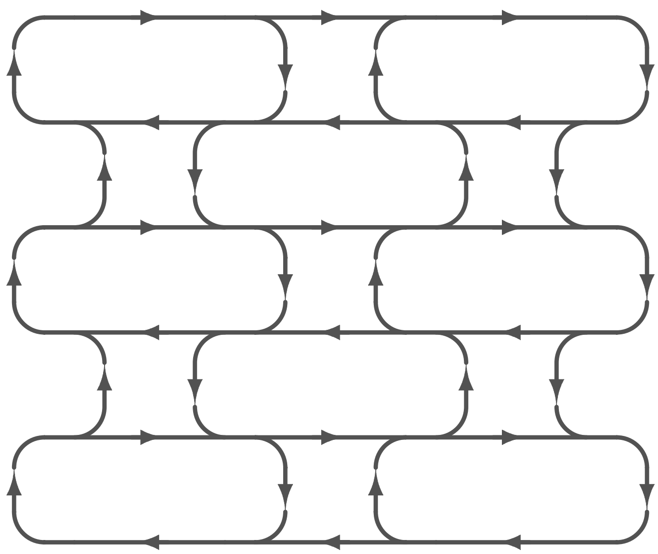

Figure 8 – Extended network of loops with 0° and 90° turns.

Another way to look at the network of Figure 8 is that at each intersection, you have a choice of a 0° or 90° turn. This suggests that an alternate approach would be to equalize the turns so that at each intersection you can turn 45° one way or the other. This is illustrated in Figure 9.

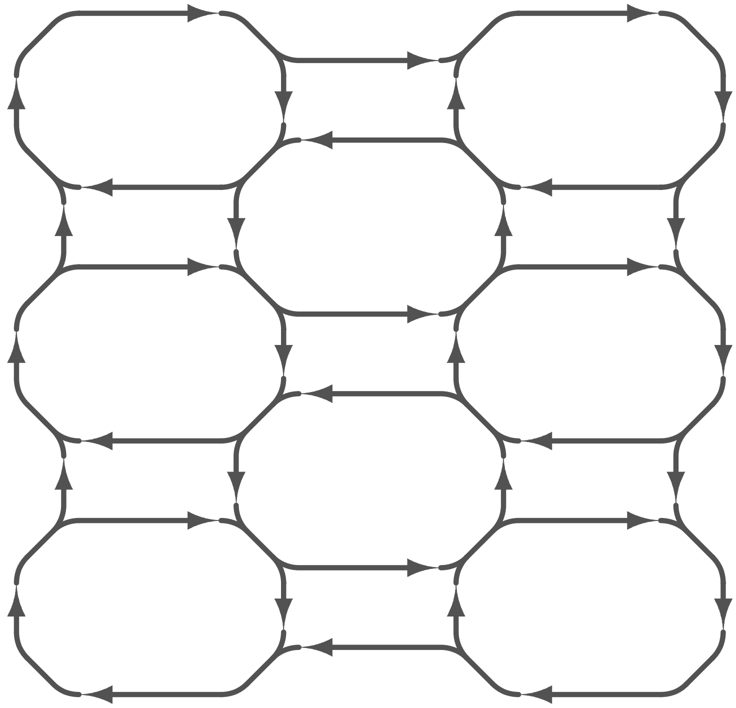

Figure 9 – Network of loops with 45° turns.

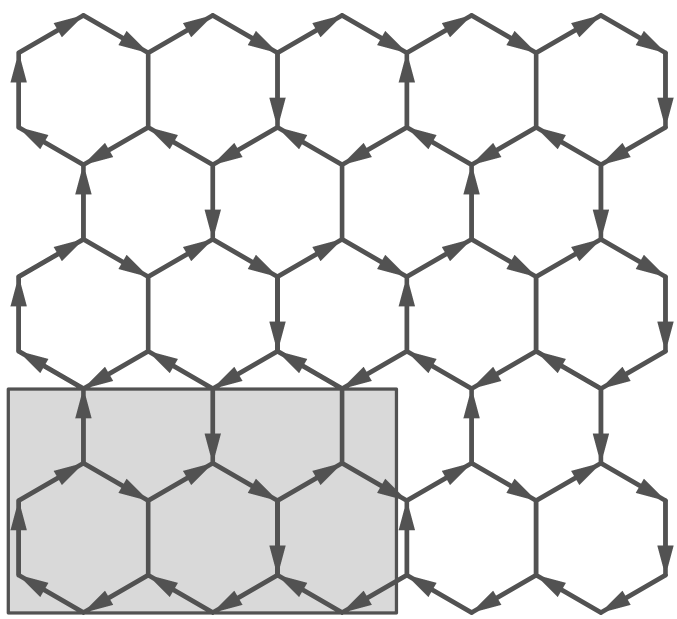

Figure 10 – A hexagonal guideway network.
Figure ?? – Hexagonal mesh guideway network with concentric rings.

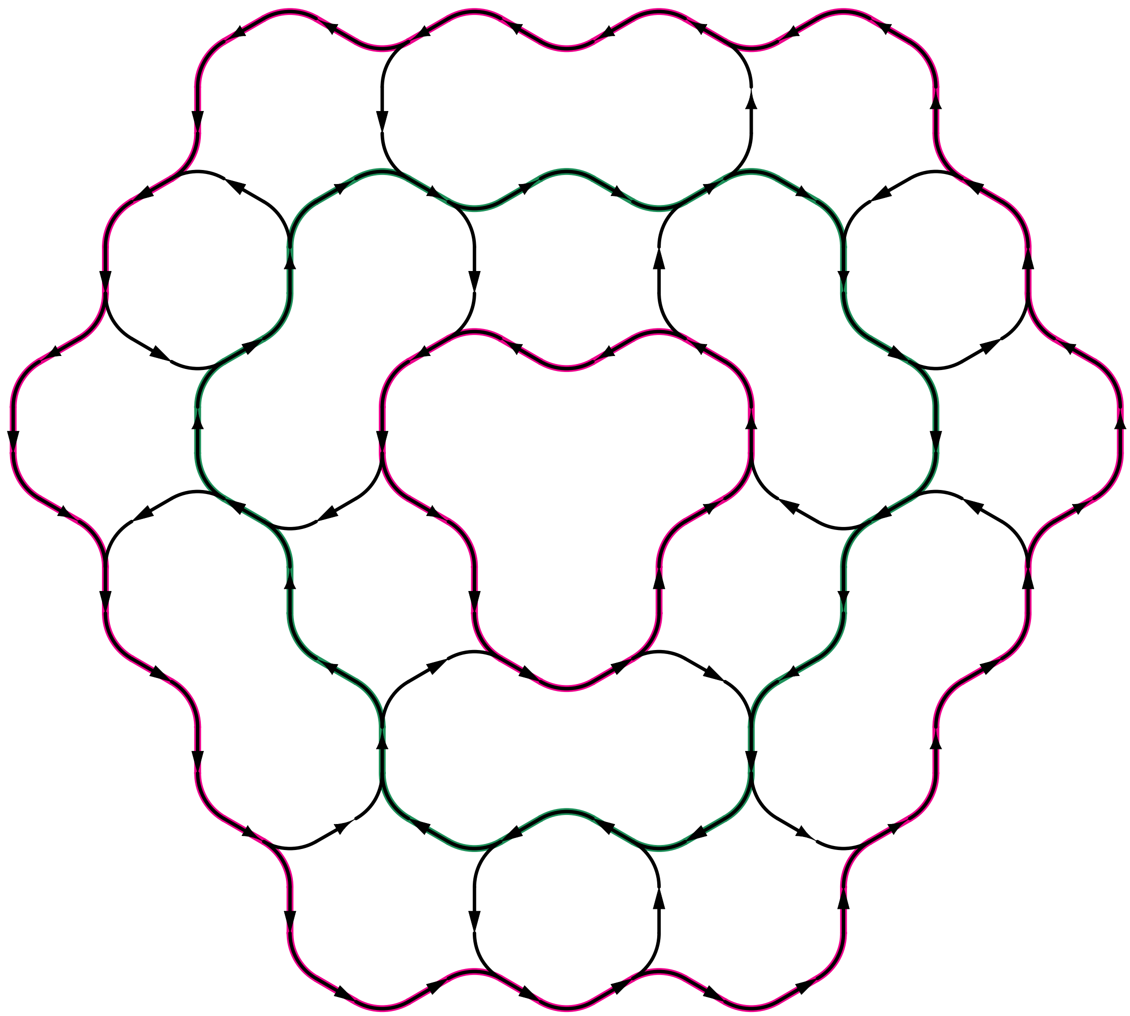

Figure ?? – Hexagonal mesh guideway network with concentric rings.

slightly below, grade with footbridges over the guideway at the points where two neighborhoods meet.

Traversing this network does involve some weaving back and forth, but since the turns are only 45° they are less noticeable. In the proportions depicted in the figure, north-south travel is about 13% further than a straight shot, and east-west travel is about 7.5% further.

Because three guideway segments meet at each intersection, it might be instructive to examine a geometric form in which this property is intrinsic: the hexagonal mesh. This would seem to be promising since our stations are arranged in a hexagonal pattern. This form is shown in Figure 10.

Bi-level Guideway Patterns

When traveling short distances, the turns that are needed to navigate a single-level guideway network do not present a problem. But for longer trips, greater ride comfort will be possible on a straight guideway. To accommodate that, we need a 2-level network. The network shown in Figure 4 has two levels, but in many situations it will have more north-south capacity than is needed. To rectify this, we can position the guideway halfway between stations, and use perpendicular sidings branching off both sides of the guideway to serve all the stations with half the number of north-south guideways. This is the pattern depicted in Figure 11.

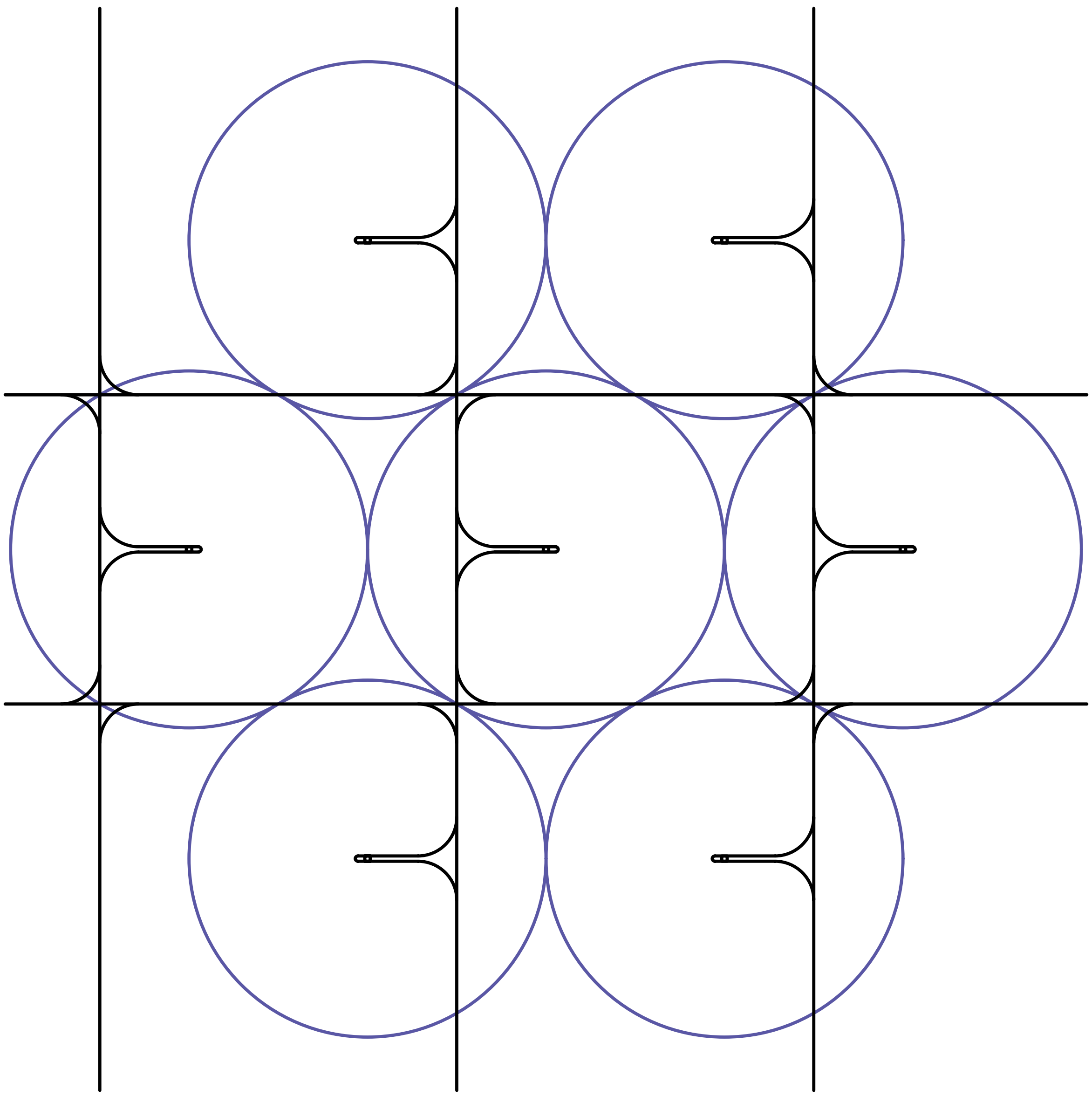

Figure 11 – Two-level guideway network.

Note that all of the sidings branch off the lower-level guideways. The upper guideways are only connectors. In this illustration the switch points are equally spaced on the north-south guideways.

Assembling the Parts Into A Car-Free Community

So far, we have been concerned mostly with issues of transportation efficiency, but there is much more to a successful development than that. If the patterns discussed above were extended over a large area, the result could be an oppressive regularity, where every place is just like every other place. A good urban design gives shape and meaning to space through relationships with distinctive features whose influence is felt throughout the community. Two such features are a defined center that serves as a *point* of reference, and a defined boundary that provides a *frame* of reference. The guideway network provides an intrinsic boundary. So we are left with the task of creating a center. The center can consist of one, two, three, or four stations as shown in Figure 12.

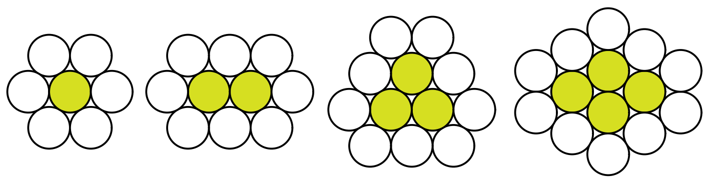

Figure 12 – Centers of one, two, three, or four stations.

For purposes of this example, we will arrange our development around a cluster of four stations. To do that, note that the guideway pattern of Figure 11 can be oriented in six different ways within the hexagonal mesh of stations. So we can use each of these orientations to surround the central core as shown in Figure 13.

This example has 164 stations. It measures 5.0 by 4.3 miles, and encompasses 10,099 acres. This is large enough that most people will feel the need for some form of mechanized transportation. The radial guideways are on the upper level, and all the stations branch off the circle lines on the lower level.

The high-density of the guideway network allows for turnarounds (equivalent to roundabouts or u-turns) that are big enough that they can be taken at high speed, and yet small enough that they do not add much to travel distance. If any station should be out of service, an alternate will be nearby. Each station is adjacent to between three and six other stations, each of which is only a ten minute walk away. Conventional forms of public transit do not offer this level of robustness. At the periphery of the development there could be parking garages and car rental facilities to provide for travel to other communities.

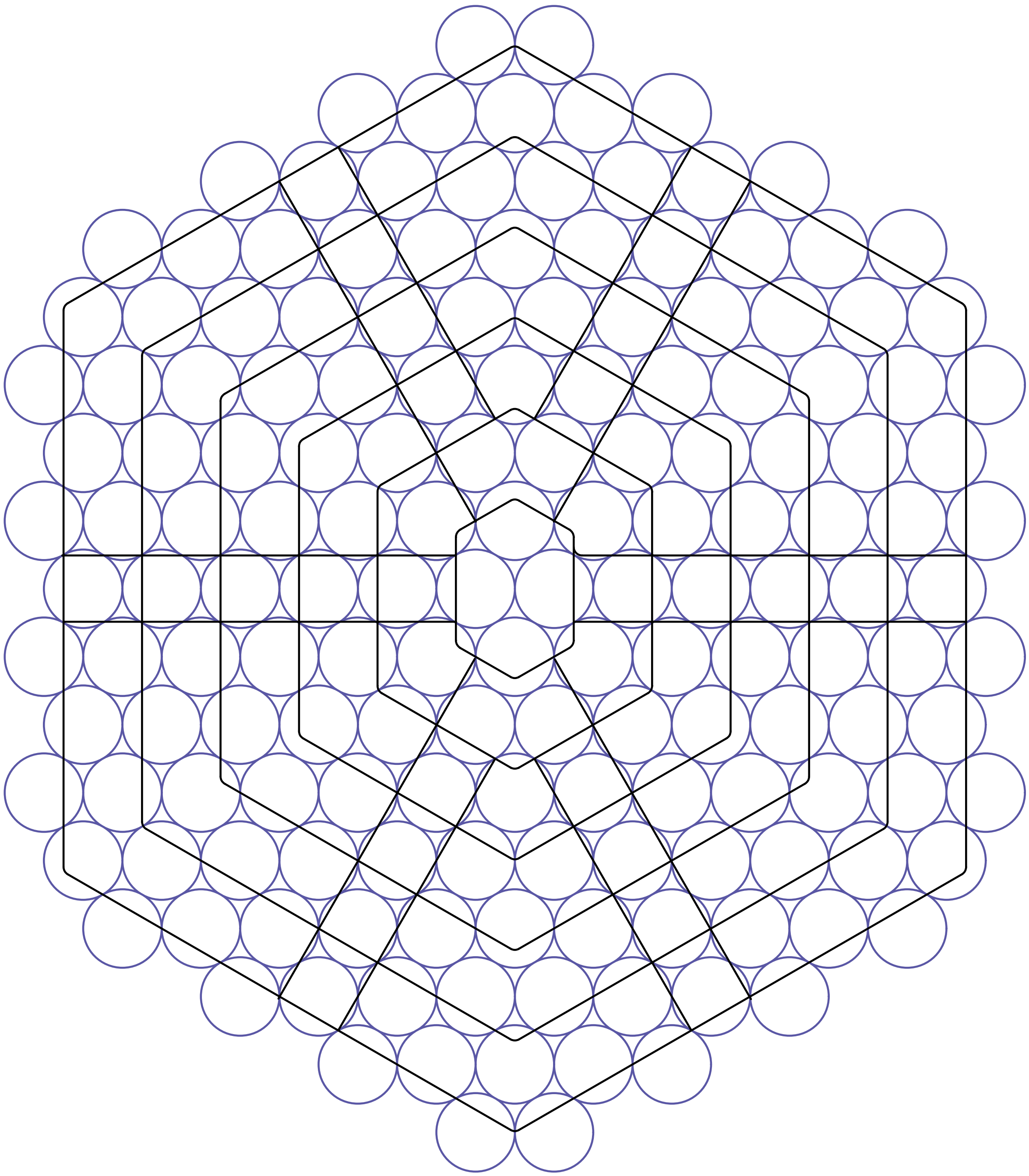

Figure 13 – An example of a car-free development.

As cities grow, traffic demand increases, but the capacity of the existing transportation infrastructure remains constant. At some point, the best option for further expansion is to build an independent community nearby (but not directly abutting) and connect it with a mass-transit system.

Implications For The Design Automated Transportation Systems

You might think that the opportunity to start with a clean slate would mean that the technical requirements of the ATN technology could be somewhat relaxed. But the foregoing design concepts suggest a few features that would be quite desirable in an ATN system.

Occupied vehicles are routed over large radius turns to maintain passenger comfort even at high speed. But there are advantages to having the ability for empty vehicles to make very tight turns, as can be seen in the design of the perpendicular station. This capability has already been successfully demonstrated in the Morgantown PRT using four-wheel steering.

In commercial areas, guideways will be mostly integrated into building, lessening concerns of "visual intrusion". In residential areas, the guideway could form a kind of portico, affording protection from the elements for pedestrians. Thus narrow guideways are not as important in new development as they are in retrofit applications.

If the pods sit atop tall bogies, then bringing them into buildings requires one of two things, either raising the guideway to the point that platform level is well above building floor level, or cutting a slot in the building floor to accommodate the bogie. The former case would necessitate the addition of steps and/or ramps that would raise issues of ADA compliance The latter case would require expensive structural modifications that would limit flexibility. This will be particularly important because new construction provides more opportunities to integrate guideways into buildings.

We have seen that in very dense networks it is often desirable to have stations branching off both side of a main guideway. One result of that is that it is useful to have doors on both sides of the pods.

In Pattern 10 with a station spacing of 1/3 mile, switch point will come about every 373 feet. At 40 miles per hour, you will pass a switch point about every 6.5 seconds. This suggests that fast switching times will be an important feature. With such frequent switching the need also arises for the operation of the switch to be undetectable to the passengers. The potential need to make an emergency stop in a short distance also suggests the desirability of ensuring that all passengers are seated.

Many people are attracted the the promise of self-driving cars to provide automated transportation without the need for any new infrastructure. Although autonomous cars can provide most of the transportation benefits of ATNs, their continued reliance on asphalt on the ground means that they do far less to improve our metropolitan environments. So the ATN guideway is not an impediment. It is the key to building communities that are healthier, safer, and more pleasant places to live.

Future Work

A kinematic analysis has not yet been performed. This calculation would start with accepted limits on acceleration and jerk that are based on ride comfort and safety, and use that to determine main guideway cruising speed.

It has not been determined how far these patterns can be extended before the transportation system becomes saturated. To determine that limit, a population density distribution could be proposed, and used to create a travel demand estimate that could in turn be used to simulate transportation system performance. By repeating this calculation for developments of various sizes, the point at which transportation demand exceeds capacity can be estimated. To serve a community larger than that, a new configuration must be used, or the intrinsic capacity of a guideway must be increased, such as by reducing vehicle headway. Beyond that, the best option is to expand into a separate, independent community nearby, as discussed above. In any case, the best results are obtained by treating transportation planning and urban planning as a single unified discipline.

Currently available ATN technology is capable of handling the passenger travel that accounts for the vast majority of road traffic. Minimizing the use of other types of road vehicles will require further study. How will packages and mail be delivered? How will large trucks be accommodated? How will trash be collected? How will emergency vehicles operate?

The ultimate goal of this inquiry will be a rigorous and objective analysis of the financial feasibility of car-free developments. But there are already reasons to suspect that the results of that study will be encouraging. It is estimated that nearly 50% of the land area of car-oriented cities is devoted to the automobile. So in a car-free development, it should be possible to have both more developable land and more green space. It is well known that property is more valuable if it is near transit, and far from high-traffic streets. Since every part of the car-free community fits that description, the entire development should fetch premium prices. And by offering a lifestyle that is not available anywhere else, the project will not be in direct competition with every other property. It will be an attractive place for businesses to locate because customers and employees will have convenient access from anywhere in the development. And the first car-free communities can be expected to receive a great deal of attention without the need for expensive marketing.

Conclusions

Naturally, car-free living will not appeal to everyone. But for those who dream of living in park-like surroundings while still enjoying the opportunities and cultural richness of the city, the kind of community envisioned here will provide a lifestyle option that is not currently available anywhere. This paper has described some design concepts that could be used to build such a community. The scale of such a project is daunting, but projects of a similar magnitude are completed successfully on a routine basis. And there is no reason to believe that the designs described here are any more challenging or expensive to build than what we are accustomed to.

Appendix A – Mathematical Properties of a Hexagonal Mesh