2. Bicycle Network Analysis: Methods

The Salt River Valley has an extensive bicycle network infrastructure, consisting of bicycle and striped and/or signed bike lanes, routes provided by cities, and shared-use paths along SRP canals. These recognized bicycle infrastructure elements are augmented by a variety of roads and provide varying degrees of safety and attractiveness for bicycling. Together, the bicycle infrastructure and street network constitute the network that bike riders navigate. This combined network, however, is not as extensive as many users and planners would like. The numerous gaps, barriers, unsafe road crossings, unpaved paths, and roads with no bicycle infrastructure pose a challenge to bicycle riders. These network problems force riders to choose between riding on more dangerous and less attractive roads and going out of their way to use a safer and more attractive route. The purpose of this study is to analyze the connectivity of the bicycle network across those parts of the valley served by SRP canals and electric service.

2.1. Route Directness Index (RDI)

We analyze connectivity using a software program called ViaCity® created by Transpo Group, a consulting company based in Kirkland, WA. ViaCity is an add-on to ArcMap 10.0 geographic information systems (GIS) software. The core concept in ViaCity is a statistic called the Route Directness Index, or RDI. The fundamental idea behind the RDI is simple, but it translates into a powerful tool for analyzing connectivity when integrated with GIS software and datasets.

RDI is calculated as the ratio between the straight line (Euclidean or “crow-flight”) distance and the shortest network travel distance following a road/path network (Figure 1):

$$RDI = \frac{a}{b} \qquad (1)$$

where:

RDI = Route Directness Index
a = straight-line distance
b = network distance

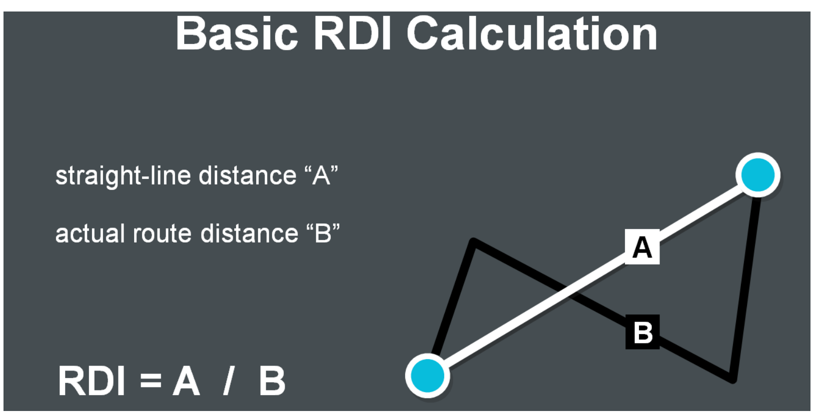
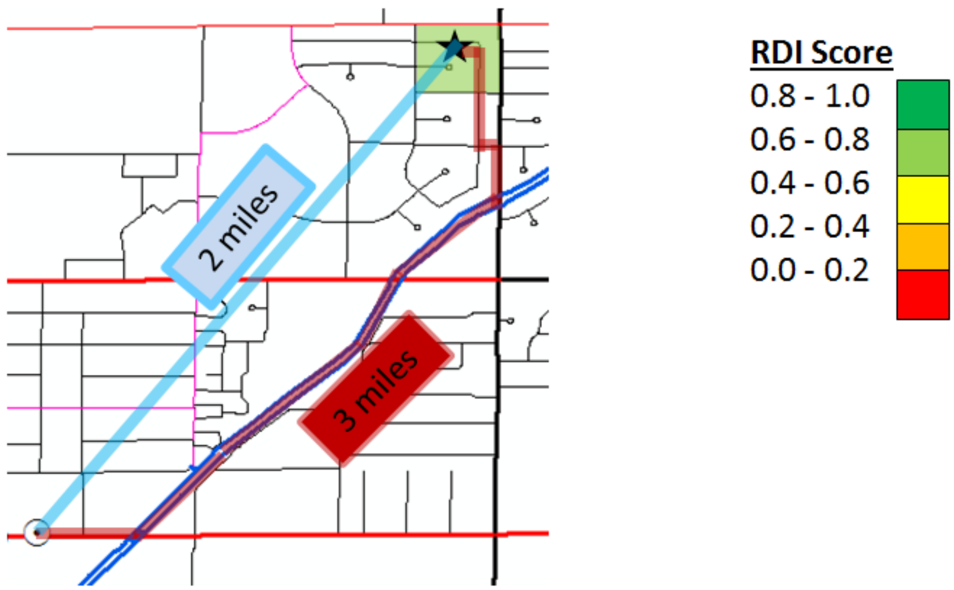


Figure 1: Basic RDI calculation (Source: Transpo Group)

Figure 2 expands on how the basic RDI idea works in GIS with polygon origins and point destinations. The blue line represents the Euclidean distance (*a* = 2 miles) if it were possible to travel from origin polygon (star) to destination point D (circle) on a perfectly straight line. The red route represents the shortest network distance (*b* = 3 miles) following roads and bike paths. Other routes exist (not shown) but they are all longer than 3 miles. The RDI for this polygon is thus 2/3 = 0.67, and the origin polygon is shaded accordingly on the map. Generally, RDI ranges from a low of 0 (an extremely indirect route) to a high of 1 (a perfectly direct route). RDI could be translated as "how much shorter the straight-line distance would be than my best available bike route."

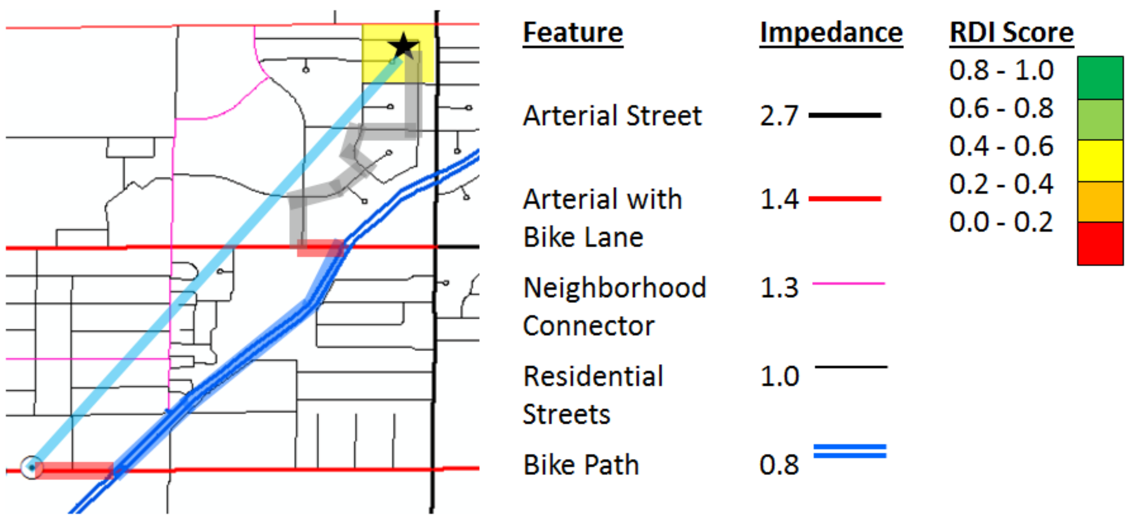


$$RDI = \frac{2}{3} = 0.667$$

Figure 2: RDI calculation from an origin polygon O to a destination point D, assuming all roads and paths are equally bikeable (distances are not exact – for illustrative purposes only).

2.2. Impedance

One of the strengths of ViaCity is the ability to treat different roads differently. A mile riding on a busy road with no shoulder is much less desirable than a mile riding on a bike lane or canal path. The general term used in ViaCity for this is *impedance*, which can be interpreted as bikeability or friction of distance (in terms of safety and enjoyment). One can think of the impedance here as "how far bicyclists would be willing to go out of their way to avoid this stretch of road." An impedance of 2.0 would indicate that the average rider would consider riding twice as far to avoid that road. An impedance less than 1.0 would indicate the opposite condition—a safe and attractive path that bicyclists would *want* to go out of their way to take. In Figure 3, we apply the impedances to the same bike route as in Figure 2. The route with the least total impedance is found. It uses local streets (impedance = 1.0), arterials with bike lanes (impedance = 1.4) and a bike path (impedance = 0.8). Multiplying the length of each section by its impedance yields a total impedance of 3.76. Despite the inclusion of this attractive bike path, the RDI for the origin polygon falls to 2/3.76 = 0.53. The origin polygon is then shaded accordingly in GIS.



$$RDI = \frac{2 \times 1.0}{(1.5 \text{ miles} \times 1.0) + (.3 \text{ miles} \times 1.4) + (1.6 \text{ miles} \times 0.8) + (.4 \text{ miles} \times 1.4)} = \frac{2}{3.76} = 0.53$$

Figure 3: RDI calculation using different impedances for different road and path types (distances are not exact – for illustrative purposes only).

A few notes of clarification about RDI:

- The hypothetical direct route is always assigned an impedance of 1.0.
- The RDI score from any origin to any destination is always based on the network route with the lowest possible total impedance.
- When using impedances in ViaCity, the lowest-impedance network route can be different from the absolute shortest network route.
- Because it is computed as the ratio of two distances, RDI is not dependent on trip length. For instance, both 2/5 and 10/25 yield the same RDI value of 0.4.
- The Data section will introduce how the impedances were set for different classes of road and different kinds of bicycle infrastructure.

2.3. GIS Calculation of RDI

ViaCity requires several types of GIS input data:

- A combined road and path network with an impedance field for each link of the network.
- A set of polygons that will serve as the origins of bike trips. These could be zip codes, census tracts, Traffic Analysis Zones (TAZs), individual parcels, or artificial grid cells. We used census

- blocks for faster computation time than using smaller parcels and more realistic bike routing than using larger census tracts. Each polygon is represented by its geographic centroid.
- One or more destinations, which can be points or polygons. We chose to analyze the connectivity of residential areas to likely bicycling destinations (points), such as educational, shopping, employment, recreation, and transportation nodes.[3]

ViaCity has flexibility to analyze different questions or scenarios, depending on how these GIS layers are developed and what assumptions are applied. In Section 3 on Data, we provide additional information on how different types of destinations are modeled in this report.

2.4. Overall Research Design

Given the network, the impedances, origin polygons, and a single destination point layer, ViaCity computes an RDI score for each origin polygon to the destination (or the closest one of a set of destinations). The RDI of each polygon can be displayed on a map. By running ViaCity multiple times, once for each destination layer, we assess how well connected each census block is to each particular destination (or type of destination). By averaging the RDI across all types of destinations, an overall picture emerges of census blocks with good, average, or poor connectivity to where bicyclists are most likely to ride.

Following this method, we produce a base case and some future scenarios. Our base case analysis reports the average RDI for each census block based on the *existing* bicycle infrastructure network. The base case highlights areas that currently have poor connectivity, that is, where indirect and/or high-impedance routes must be taken to many types of destinations.

We then analyze a number of future scenarios for new bicycle infrastructure investments. By differencing the average RDI map for the base case and the average RDI maps for the new scenarios, we identify which areas would improve their connectivity the most and which areas would not benefit significantly. Transpo Group refers to this as “delta” analysis, or analysis of the change produced by new bicycle infrastructure.

2.5. Strengths and Limitations of RDI Analysis

When interpreting the results of RDI analysis, it is important to recognize the strengths and weaknesses of the method. The strengths of RDI and ViaCity lie in its simplicity, flexibility, level of detail, focus on network connectivity, and computational power.

- The simplicity stems from the fact that RDI measures connectivity using a simple ratio of the hypothetical direct “crow-flight” bike route and the actual best bike route.
- Its flexibility lies in the ability to set impedances for each unit of distance traveled on different kinds of roads and bicycle infrastructure. Additional flexibility is afforded by the types of origin polygons and destination points analyzed.
- For analyzing bicycling, accurate geographic detail is of the utmost importance. Short blockages can cause long detours or funnel riders onto unsafe thoroughfares or shortcuts. ViaCity analyzes

[3] ViaCity can also analyze the connectivity of every polygon to every other polygon and display the average RDI of each polygon to all others.

connectivity at the level of every individual street and path. A small cut-through or short bike lane can produce measureable improvements in connectivity.

- RDI measures *only* network connectivity. It doesn't "muddy the waters" by taking things into account that bicycle planners cannot control, such as proximity of the destinations or demographics of neighborhoods. Bicycle infrastructure planning cannot address how close the nearest shopping center, business district, or community college is to any particular neighborhood. Nor does it address how many people live in a certain neighborhood, or whether the residents are more or less likely to use bicycles. What RDI focuses on is how directly the network infrastructure enables a resident of a given area to make a trip by bicycle to whatever destinations are closest to that neighborhood.
- ViaCity automates numerous steps of this process, such as building the network topology, quality checking the network, finding the closest destination to each polygon, running all the shortest paths, calculating the RDIs, and adding the results fields to the polygon feature class for GIS display purposes. It can do this for huge numbers of arc, nodes, origin polygons, and destination points. Run times ranged from 10-20 seconds for the 17x17 analysis of SRP inter-facility travel, to 1-5 hours for 14,000 origins to 100 or more destinations, depending on the memory and speed of the computer.

The limitations of RDI are, in some ways, side effects of the strengths. The RDI ratio is simple and easy to understand. It is designed to be independent of distance, and thus it measures the need for detouring in relative rather than absolute terms. For very short trips, a small detour can lead to an exaggerated, disproportionally low RDI score. This is illustrated in Figure 4, where the effect of a detour of one city block is shown for a short trip of one block and a longer trip of 10 blocks. Assuming an impedance of 1.0 on all routes, the one-block detour has an RDI score of 1/3=0.33 for the short trip and 10/12= .833 for the longer trip. Thus, in viewing RDI maps, one will often notice low RDI scores in close proximity to the destination. This counter-intuitive result is confusing unless one keeps in mind that for short trips, a small detour in terms of absolute distance can be a large detour in relative terms given the very short hypothetical direct distance. This is a key difference between measuring connectivity and distance.

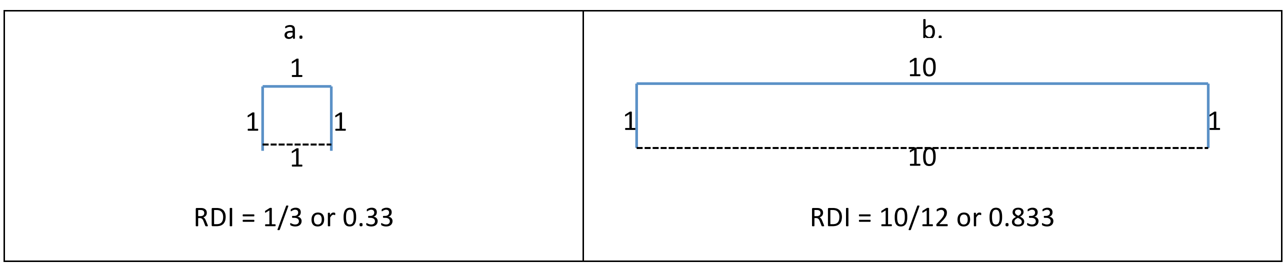


Figure 4: Illustration of the effect of a 1-block detour on the RDI score for destinations (a) 1-block away and (b) 10 blocks away.

A second limitation stems from the fact that the RDI score for the entire polygon is computed from the geographic centroid of the polygon. The centroid itself may fall between the links of the network. ViaCity finds the centroid and then finds the closest part of the network and connects the centroid to it with an artificial connector link with impedance of 1.0. Again, for a nearby destination, this connector may create a route that goes in the opposite direction from the destination, or in the same direction, or a perpendicular direction. For short trips, this connector piece could cause one polygon near the destination to have a low RDI score while another nearby polygon has a much higher RDI. Some parts of the polygon might have very direct or low-impedance connectivity to a nearby destination, while other areas may have indirect or high-impedance connectivity. In addition to measuring the effects of directness and impedance, a polygon's RDI score depends on the shape of the polygon, where the centroid happens to fall, and the density of the network in the vicinity of the centroid. These kinds of factors can, in some cases, create an exaggerated low RDI score for nearby destinations, but tend to have less effect on the RDI ratio for more distance destinations.

As a result of these two key points, **the RDI maps for any particular type of destination need to be interpreted with caution**. Low or highly variable RDI scores for polygons immediately surrounding any destination should be taken with a grain of salt. For this reason, the composite RDI maps are far more useful for planning purposes than any single RDI map for a single type of destination. The composite maps show the average RDI for many types of destinations, which could be near or far from a polygon and in any direction. **By averaging the RDI over many destinations at various distances and in various directions, the composite RDI gives a more complete and consistent picture of the polygon's connectivity generally.** If a polygon gets consistently low RDI scores over many kinds of destinations, its best bike routes are either blocked or forced to take high-impedance roads in most directions, or most of its closest destinations are consistently more difficult to get to than one would expect given how far away they are.

As a result of these strengths and weaknesses, what our RDI analysis is most useful for is identifying neighborhoods that have consistently poor connectivity to a suite of likely biking destinations, regardless of how close or far away those destinations are. In addition, by doing the analysis before and after bicycle infrastructure improvements, it is possible to measure in a simple, flexible, and detailed way what the effect of those improvements are on neighborhoods both near and far from the network improvement.