ROUNDABOUTS IN DAVIS
A COMPREHENSIVE POLICY ANALYSIS

DAVID ZETLAND

Contents

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1. Problem Definition

You have just exited Interstate 80 and are headed to downtown Davis. You have to stop, however, for a red light at the "worst" intersection in Davis. You wait as the green light blesses one direction at a time. Don't you hate waiting? Drivers waiting at the other two red lights hate it too. Bikes hate this intersection because they cannot make a right turn to go under the railroad tracks and must go straight. They get hit by cars, whose drivers are worried about bicyclists and other drivers trying to make a turn before they get caught behind that light for a minute and forty-five seconds.

In this analysis, I will examine *traffic control*[1] alternatives that can improve situations like this using at two intersections in Davis as examples. My primary alternative is the roundabout design, which lowers top speeds, increases average speeds, and results in safer and more satisfying traffic flow for drivers, bicyclists, pedestrians and neighborhood residents.

1.1. Summary Definition.

Inappropriate traffic control methods *resulting from* planning inertia *leads to* inefficient, less safe, and unsatisfactory transport experiences for residents and commuters in Davis.

1.2. Detail.

While most of us are not going to experience an accident in Davis, all of us will use the streets to move around the city. This

[1] A traffic-control system "is to promote highway safety, efficiency, and uniformity so that traffic can move efficiently on the Nation's streets and highways," says the Federal Highway Administration (`http://mutcd.fhwa.dot.gov/kno-faq.htm`).

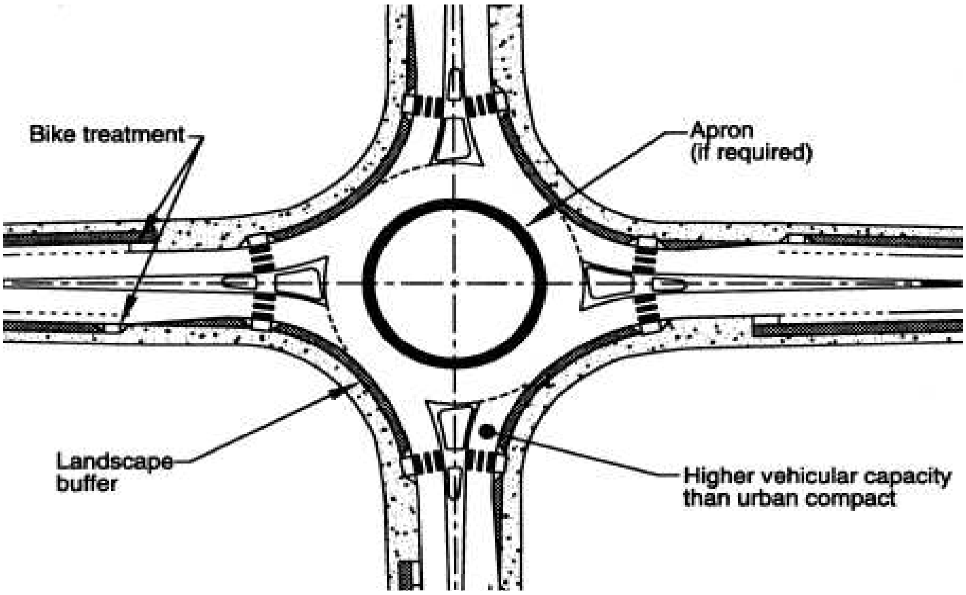

FIGURE 1. An Urban Single-Lane Roundabout has an inscribed circle diameter of 30-40 meters, allows a 35 kmh entry speed and 20,000 vehicles per day. The busiest Davis intersections have about 25,000 vehicles per day (PWD, 2005).

experience can be frustrating when the rules appear to be “out of sync” with the needs of commuters (pedestrians, bicyclists and motorists). Rules, which are most obvious at intersections, slow us down, let others go too fast or just get in the way to a satisfactory experience. One often neglected aspect to ill-formed rules is their impact on non-commuters, i.e., the people who are living in areas with traffic circulation.

This analysis will consider how roundabouts can improve the experience of commuters and non-commuters alike. See Figure 1 for a typical example of a roundabout.

1.3. **Evidence of a Problem.** Since government is in charge of this public good (roads), inadequate provision of road services is a government failure that needs attention. The evidence of a problem with respect to traffic circulation is both quantitative and qualitative. Inefficient traffic circulation (measured by delay or variation in speeds at intersections) and accidents can be measured qualitatively. Driver frustration, pedestrian and bicyclist reports of "perceived security," and neighborhood satisfaction with traffic are all qualitative measures.

While I do not have data of either type,[2] there is frustration with traffic circulation in Davis—especially at intersections similar to those in this study.[3] Since this analysis is counterfactual, I will use data from roundabouts in other locations to show what quantitative changes might occur and general reasoning to support potential qualitative improvements.

I evaluate two intersections: Richards Boulevard at Olive Drive (Figures 2 and 3) and A Street at 3^{rd} Street (Figures 4 and 5). At each location, I will describe the current situation, what could be improved and the feasibility of an improvement. I choose the first intersection because it is "the worst" and the second because bicycles and cars are in constant conflict. Table 1 gives accident statistics for Richards at

[2]I have personal experience and anecdotal evidence to draw on here. (See e.g., Talevich et al. (2005)).

[3]There are numerous other intersections that I could have chosen; instead I use two examples to "prove" the concept.

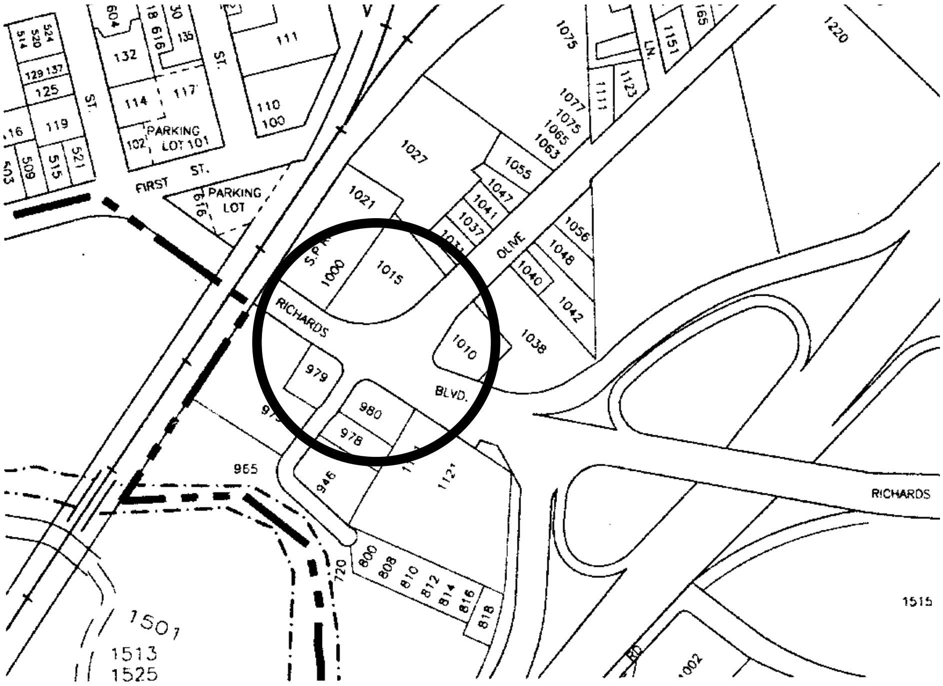

FIGURE 2. Richards Boulevard at Olive Drive, "the worst intersection in Davis" due to left-turn delays, mismatched speeds of drivers exiting the freeway and leaving the residential areas, and heavy bicycle traffic (Talevich et al., 2005).

TABLE 1. Richards Blvd/Olive Drive accident statistics for five years (2000-2004) 18 of 43 were injury accidents, 5 of which invloved bicyclists ("other") (DPD, 2005).

	2000-4	Annual Average
Rear-Ender	25	5
Broadside/Head-on	8	1.6
Other	10	2

Olive from 2000-2004 data. Table 2 gives traffic flow statistics for each intersection.[4]

[4](A)ADT means "(Annual) Average Daily Traffic." This information will be useful when comparing quantitative differences between alternatives.

FIGURE 3. View from Olive, west of Richards, looking east. Downtown Davis is to the left. I-80 is to the right.

TABLE 2. Average Daily Traffic (ADT) volumes at subject intersections (PWD, 2005).

Street	Date	ADT
Richards Blvd S/O 1st St	4/12/2004	23264
Olive Dr @ 1280 Olive Dr	2/10/2004	2907
A St N/O 3rd St	10/3/2000	3250

1.4. **Underlying Causes.** Economists have concluded from observation that people prefer the average to the extreme. This concept is most often used in risk analysis—where a "risk-averse" individual prefers to have the average jackpot without risk rather than gamble until winning the average jackpot in a series of wins and losses (Kahneman and Tversky, 1979). With traffic flow, the implication is that commuters

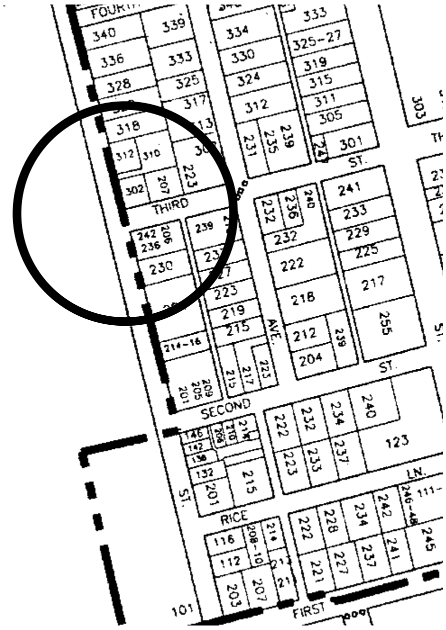

FIGURE 4. A Street at 3^{rd} Street, where heavy east-west bike traffic to and from the Davis campus crosses the northbound one-way street at an intersection with three often ignored stop signs.

prefer to go at a steady speed rather than speed up and slow down around that steady speed.[5] For similar reasons, non-commuters prefer that cars have a low variation in speeds so that they are more predictable when traveling through the neighborhood. By design, traffic signals and stop signs increase variation and create discomfort. This discomfort grows in intensity if the variation is mismatched with the actual traffic flow—creating pressure points for intervention.

[5]It is common knowledge that freeway accidents attributed to speed are caused by variation in speed, not absolute speeds.

FIGURE 5. View of A Street, north of 3^{rd}, looking south. Downtown Davis is left. UC Davis is right.

1.5. **Past Efforts to Resolve.** Past efforts to resolve the "variation problem" have included signal synchronization, widening roads, separating cars from *non-cars* (bicycles, pedestrians and non-commuters), building bypasses and greater use of speed limits and law enforcement.[6] Unfortunately, each of these "solutions" has made the situation worse

[6] "There are widely held misconceptions that speed limit signs will slow the speed of traffic, reduce accidents, and increase safety. Most drivers drive at a speed that they consider being comfortable, regardless of the posted speed limit. 'Before and after' studies have shown that there are no significant changes in vehicle speeds following the posting of new or revised speed limits. Furthermore, research has found no direct relationship between posted speed limits and accident frequency." From `http://www.city.davis.ca.us/pw/traffic/speedlimit.cfm`

because they build in a higher variation between cars and non-cars—aggravating variation on a different dimension when (inevitably) cars and non-cars clash.

Curiously, this problem arises from an early notion that cars and non-cars should be separated for the sake of efficiency. While it is true that cars operating at very high speeds are dangerous to non-cars, it is also true that cars interact with non-cars all the time—especially at the beginning or end of their trips. Cars and non-cars should not interact based on car efficiency but as a balanced system that takes the needs of all into consideration. This requires a rethink of traffic flow, which roundabouts facilitate. Since roundabouts increase average speed, drivers are less frustrated and dangerous (Yagil, 2004).[7]

1.6. **Political Background.** Traffic flow is dominated by an engineering perspective of command-and-control efficiency. Alternative perspectives of balance and cooperation (more familiar in biology or sociology) are often dismissed as dangerous or unrealistic; they are merely unfamiliar (Engwicht, 2005). In addition, drivers common desire to stay in charge of *their* environment means that efforts to "calm" traffic represent assaults on their sovereignty (Lehner, 1998). Another barrier

[7]While "78 percent were satisfied with the city's effort to coordinate traffic signals," some residents hate traffic-calming devices (City of Davis Final Budget 2003-4, pp 17-18; see, e.g., `http://daviswiki.org/Driving_in_DavisTrafficSlowingMeasures`). The unhappy 22 percent can cause accidents through their impatience.

to change is that of path-dependence or status quo, i.e., that entire generations of engineers, police and drivers would have to learn a different style of traffic flow. This is not true in practice (Engwicht, 2005).

1.7. **The Client.** The Davis City Council wants to improve the quality of life in Davis. One area that concerns them is the effects of traffic on driver satisfaction, resident safety and community livability.

2. Alternatives

In this analysis, I will discuss several alternatives for making intersections (and traffic flow in general) work better for cars and non-cars.

Do nothing: This is the baseline scenario to improve and assumes that traffic signals or signs are optimally configured.

Better Enforcement: Enforcement is not the problem at intersections, as most people obey the traffic laws that apply. Since there is no law which states that one must move through the intersection with the greatest efficiency, enforcement will not make traffic flow any better. (Technically, it is legal to be in the intersection when the light turns yellow, so enforcement cannot improve problems with left turns.) At A and 3^{rd} streets, enforcement would *reduce* traffic flow, as east- and westbound bicyclists would stop without need, since there are not always cars waiting to go northbound. (Dangerous encounters between bicyclists and cars at this intersection are often caused by the drivers' desire to go and the bicyclists desire not to stop.) More importantly, the threat of enforcement would have little effect when drivers are impatient after "too much" delay.[8]

Increase Capacity: The intersections that I am analyzing do not have space for extra lanes. Even if they did, capacity would not fix the coordination problem at the intersection.

Install Roundabouts: Roundabouts change the way that cars and non-cars interact at intersections. The resulting balance is similar to that of an ecosystem: natural balance arising from simple rules. (Roundabouts are not traffic circles; the former are about traffic control, the latter about calming.[9])

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[8]Yagil (2004) reviews the literature on driver psychology. There is controversy over how drivers actually behave or think with respect to traffic laws. One assumption is that traffic laws contribute to driver safety or that drivers violate them when the benefits exceed the costs. This assumption does not hold when laws allocate blame, are banal or encourage rebellious behavior. A far more interesting assumption is that people obey laws because authority says they should. As far as this analysis is concerned, we must consider that drivers will break centrally imposed, illegitimate, or unpopular laws. It is not hard to understand why they hate long waits while other cars flow by—this situation violates the primitive premise of fairness (Brosnan and Waal, 2003). Well-designed traffic control decreases unlawful behavior, reducing cognitive dissonance and increasing respect for other, more useful, forms of authority.

[9]Roundabout (Traffic Circle) Characteristics (Robinson et al., 2000, pp. 8-12):

- Yield control is used on all entries. The circulatory roadway has no control. (May use stop control, or no control, on one or more entries.)
- Circulating vehicles have the right-of-way. (May require circulating traffic to yield to entering traffic.)
- Pedestrian access is allowed only across the legs of the roundabout, behind the yield line. (May allow pedestrian access to the central island.)
- No parking is allowed within the circulatory roadway or at the entries. (May allow parking within the circulatory roadway.)
- All vehicles circulate counter-clockwise and pass to the right of the central island. (May allow left-turning vehicles to pass to the left of the central island.)

2.1. **Does Davis Need This?** In the 1960s, Davis was the first city in the United States to paint bike lanes on city streets. It is still praised for progressive policies:[10]

> Peter Bejger: What impressed me is that there's a lot of intelligent urban planning. It's good to see bicycles fitting into urban planning.
> Michael Cobb: What I also like here [in Davis] is that there seems to be less of an antagonistic relationship between bikes and cars like you sometimes see in the City [San Francisco]. It seems like people here are used to the bikes and don't have a problem with them.[11]

It is ironic that Davis (home of the UCD Institute of Transportation Studies) uses traffic-control devices that hinder the quality of life.[12]

3. Description and Analysis of the System

3.1. **Evaluation Criteria.** I will augment benefit-cost analysis of the alternatives with some qualitative information, i.e., by examining:

Traffic flow (delay): Measure the mean and variance for travel time through the intersection.

Driver/Bicyclist/Pedestrian safety: Measure the number and costs of accidents. Accidents underestimate the cost of safety if we consider "feelings" of security to be important.

[10] Davis has statistics to match: "Davis has established itself as 'America's Best Cycling City'(Bicycle Federation of America, 1995). With an area just over ten square miles, Davis has 48.8 miles of bike lanes and 49 miles of bike paths. More than 80 percent of all collector and arterial streets within the city have bike lanes and/or bike paths. This is the highest such ratio of any city in the country! . . . With a population of 55,000 residents, it is estimated there are over 50,000 bikes in the city of Davis" (Bustos, 2001).

[11] Bejger and Cobb are members of Different Spokes, a lesbian, gay, bisexual and transgender bike club in San Francisco (O'Hara, 2002).

[12] For the moment, I ignore exceptions such as the bike bridges, three retro-fitted roundabouts and the bike-traffic signal.

Installation and maintenance costs: Measure initial and annual expenditure.

Quality of life: This qualitative characteristic is hard to quantify. At the moment, I will use my common sense; an extended version of this analysis would survey commuters and non-commuters to find their valuations of various aspects of each alternative.[13]

3.2. **Systems Analysis.** The primary goal of this section is to relate exogenous and endogenous variables to each other in a system that shows how (**exogenous**, in **bold**) fixed characteristics and (endogenous) choices affect each other and how change can alter the equilibrium. First, I list the variables of interest; second, I show and describe how they affect each other; and third, I show how the alternative (roundabout) will produce a different result. (In Section 4, I discuss this thoroughly.)

3.2.1. *Variables.*

Users: Mean (ADT) and variance of cars, bicycles, and pedestrians, in quantity and speed. **Direction of travel** (origin and destination with respect to the intersection). **Neighborhood characteristics** (population density, number of children, and types of transportation) near intersections.

[13]These valuations might capture feelings about quantitative differences as well as the effects of designs on community and personal harmony (Yagil, 2004). See Engwicht (2005) for a brief discussion of how traffic and community, drivers and nondrivers must be treated together as an ecosystem.

Environment: Dimensions of the intersection, **natural** (buildings) and artificial (traffic control devices) barriers to movement.

Psychological: Legal, social and individual attitudes towards movement in the intersection and towards violation of others' attitudes.

Economical: Costs to install and operate alternatives. Costs to users for normal and accidental activities under each alternative. Externality costs (pollution, noise, spillovers to other areas).

3.2.2. *Cause-effect Relationships.* Figure 6 shows the causal relationships between the variables. The most-important relationship is the feedback of delay, accident and externality costs that result from and impacts drivers', bicyclists' and pedestrians' use of the intersection. If those costs are high, they put political pressure for a change of traffic control device. Neighbors affected by externalities can also put on pressure (no arrow showing this).

3.2.3. *Consequences of Alternatives.* If the cost of using signals (or stop sign, if you consider A Street and 3^{rd}), rises too high (in terms of safety, delay or quality of life), then there will be pressure to find a solution. Roundabouts are offered as one alternative here, as they have superior performance with respect to these features. (See Section 4.) Public and political acceptance will not be a function so much of familiarity but of

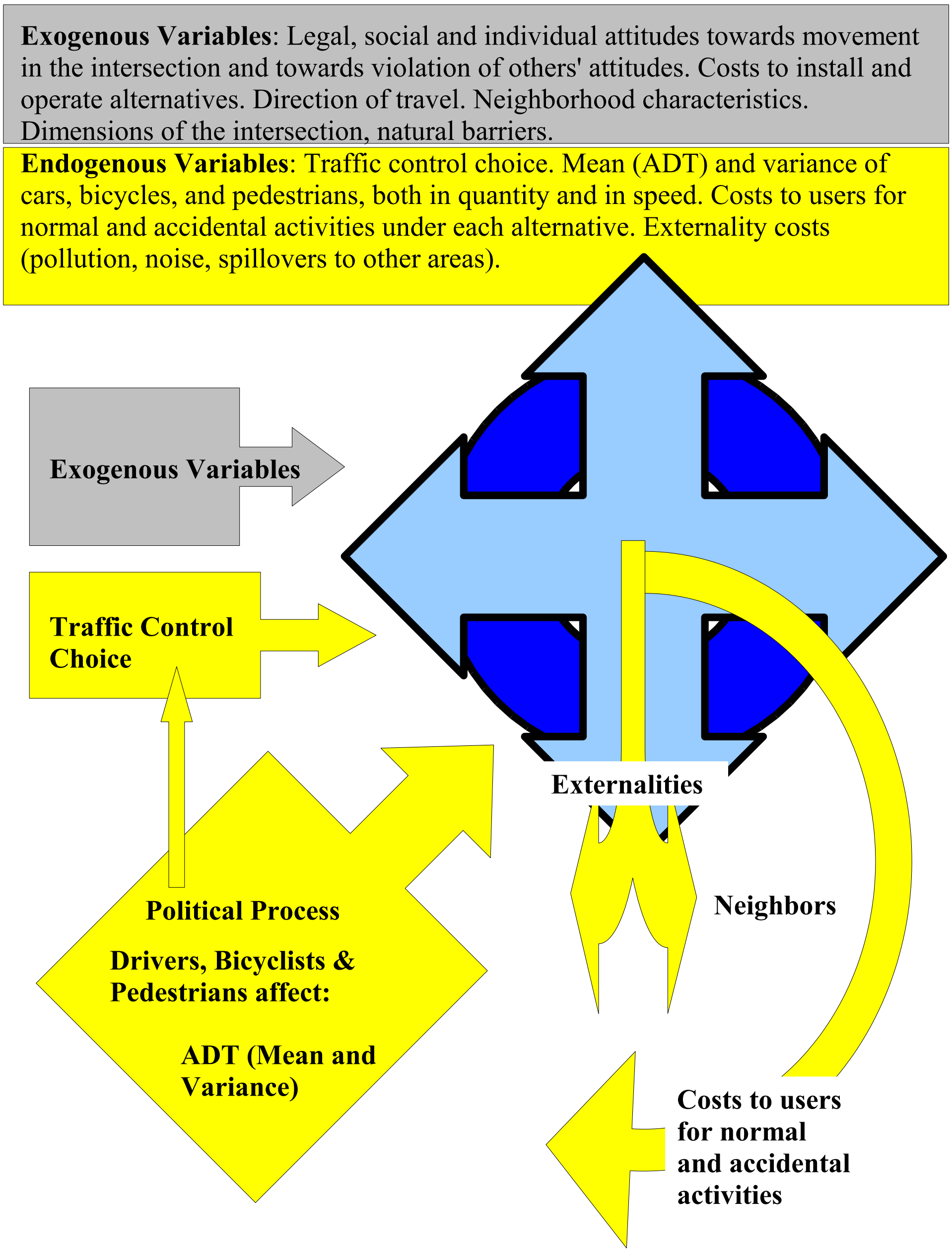

FIGURE 6. Cause-effect relationships between exogenous and endogenous variables, as they interact in the traffic control system (either signal or roundabout).

cost and overcoming inertia. Given Davis' proactive stance on traffic issues and healthy finances, acceptance will probably depend on believable prospects for improvement. There will be a "breaking in" period (those single-car accidents) after the discomfort of construction,[14] but this is inevitable and part of the benefit-cost analysis.

4. Round Versus Square Interactions at Intersections

According to Francisco (2005), the reasons in favor of a roundabout are increased safety from a reduced number of broadside accidents. The reasons against are that roundabouts need more space, large vehicles have a hard time turning in them, and driver inexperience in using them.[15] They are particularly suitable for intersections with capacity problems, high accidents (especially left turn) [Richardson and Olive], four-way stops, or areas with a heavy delay on side streets [A Street and 3^{rd}]. The Federal Highway Administration Roundabout Informational Guide (Robinson et al., 2000, pp. 24–26) says that "lower circulating speeds can provide greater operating capacity" and that "roundabouts eliminate crossing conflicts by converting all movements to right turns." Lenters and Weber (2004, p. 3) agree. This latter characteristic is one

[14]This can be minimized by hacking out spaces on the corners before claiming the middle of the intersection and *then* making permanent improvements after users have adjusted to the new scenario.

[15]He said that the most recent retrofitted roundabout was at Anderson and Alvarado; it was to increase the safety of drivers, bicyclists and pedestrians exiting from side streets across a road with fast traffic, while increasing traffic flow—all at a lower cost than a "non-warranted" traffic signal (Pelz and Flecker, 1996).

reason why drivers, pedestrians, and bicyclists have an easier time in roundabouts—there's only one place to look.

4.1. **Flow.** Robinson et al. (2000, p. 62) say that "a roundabout will always provide a higher capacity and lower delays than an *AWSC* (All Way Stop Controlled) intersection operating with the same traffic volumes and right-of-way limitations." (See Figure 7.) A substantial part this benefit comes during off-peak periods (Robinson et al., 2000, p. 65). This benefit stands when roundabouts are compared with *signalized* intersections: "A roundabout will provide better operational performance than a signal in terms of stops, delay, fuel consumption, and pollution emissions... provided the roundabout is operating within its capacity" (Robinson et al., 2000, pp. 67). Figure 8 applies to Richards and Olive, which has about 23,000 ADT and ten percent left turns.

Flow efficiency is the direct result of a more human approach. Common reminders of failures in signal design are waiting at a red light at midnight or easing into the intersection on a yellow light to make a left. Less structure (and information) can lead to more efficient outcomes when human randomness is introduced (Klügl et al., 2003). That is, fewer restrictions leave responsibility for navigating the intersection to users; since it is in their best interests to get through the intersection without hitting each other, they will find the least cost way appropriate to the current conditions. (Mechanistic solutions can lead to coordination problems when following the rules interferes with navigating the intersection.)

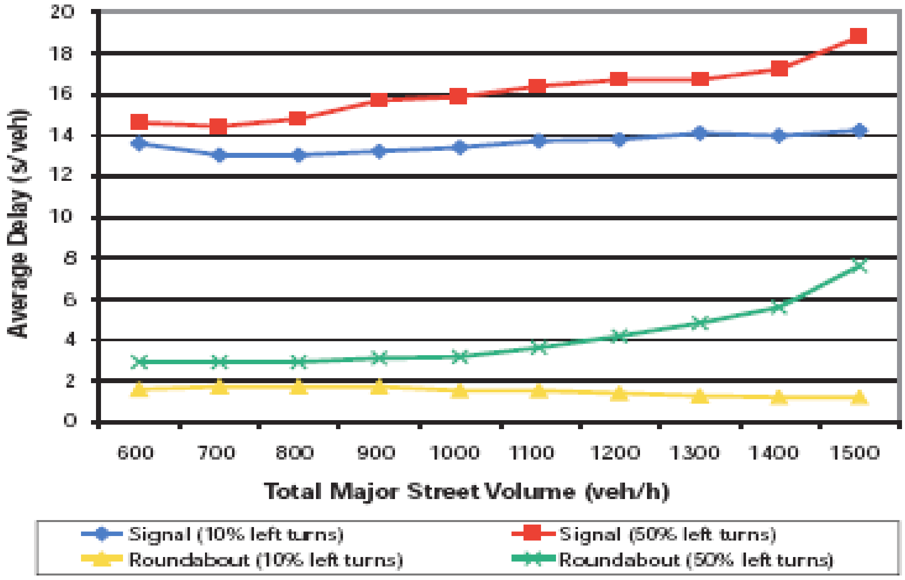

FIGURE 7. "Roundabout approach delay is relatively insensitive to total major street volume but is sensitive to the left turn percentage." Average delay per vehicle at the peak hour signal threshold (Robinson et al., 2000, Exhibit 3-7 on p. 63).

4.2. **Safety.** "In comparison to signalized intersections, roundabouts may experience approximately 33 percent fewer injury crashes in urban and suburban areas for 20,000 entering ADT" (Robinson et al., 2000, pp. 60-61). Roundabouts remove many potential areas of conflict, between cars (Figure 9) and cars and pedestrians (Figure 10).

In a study of 24 intersections, Persaud et al. (2000) estimated highly significant reductions of 39 percent for all crash severities and 76 percent for all injury crashes. (Reductions in the numbers of fatal and incapacitating injury crashes were estimated to be about 90 percent.) Neiderhauser et al. (1997, p. 8) agree: "Modern roundabouts have been

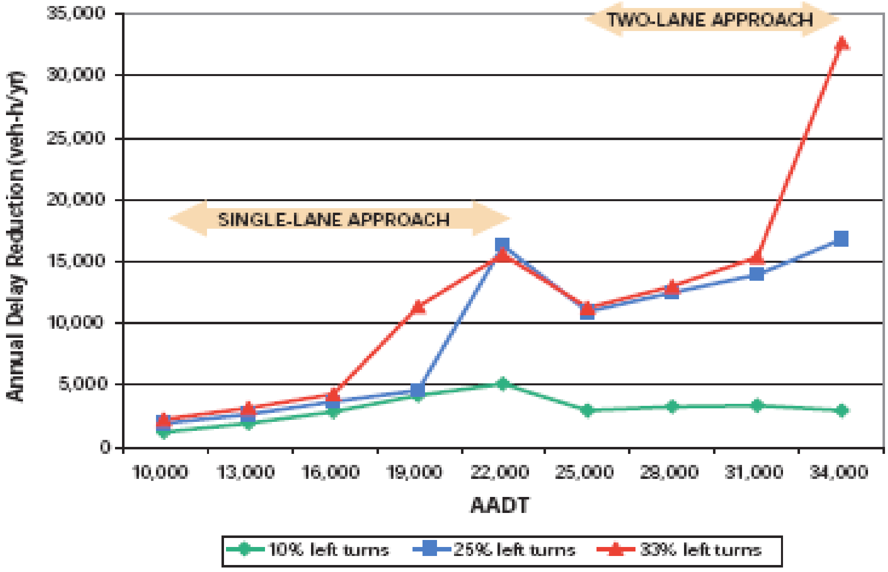

FIGURE 8. "When the major street approaches dominate, roundabout delay is lower than signal delay, particularly at the upper volume limit for single lane approaches and when there is a high proportion of left turns. [Delay savings for roundabout versus signal, 65 percent volume on major street.]" (Robinson et al., 2000, Exhibit 3-13 on p. 69).

proven worldwide be the safest form of intersection control." Injury accidents fell by 34 to 78 percent when intersections were converted to roundabouts in seven different countries. The intensity of damage in remaining accidents was also lower—damages fell by about 30 percent because left-turn accidents were eliminated and angle accidents fell by 80 percent. The only drawback appears to be more single car crashes. (Apparently drivers fail to go *around*.)

4.2.1. *Bicyclists.* In an early study comparing bicycle-car collisions in Davis (with bike lanes) to Santa Barbara (without bike lanes), Lott

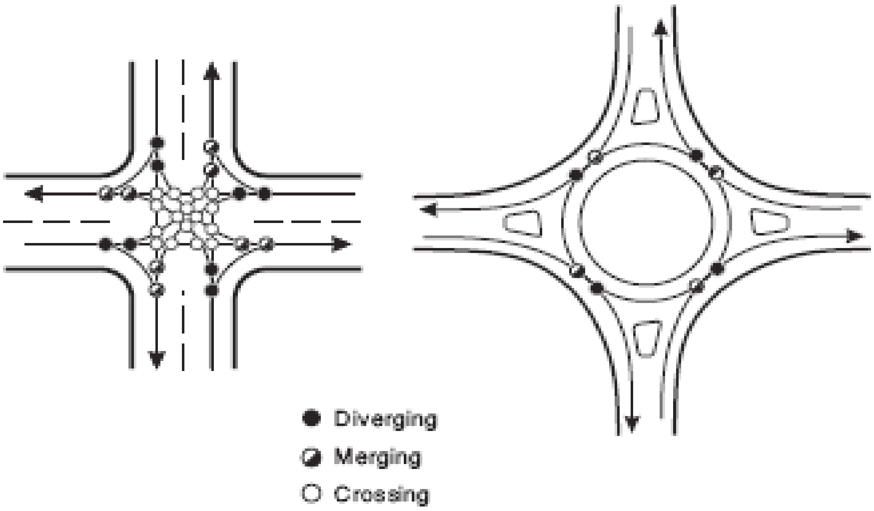

Figure 9. A four-leg single lane roundabout has 75 percent fewer vehicle conflict points compared to a conventional intersection (Robinson et al., 2000, Exhibit 5-2 on p. 106).

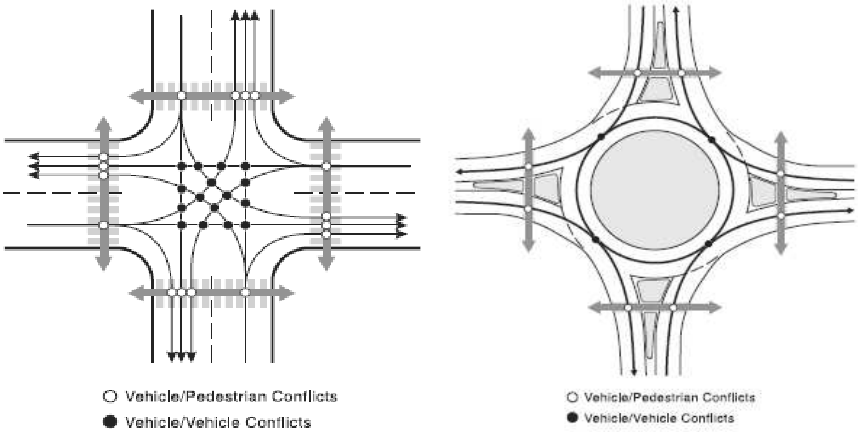

Figure 10. A comparison of vehicle—pedestrian conflicts at signalized and single-lane-roundabout intersections (Robinson et al., 2000, Exhibits 5-5 and 5-6 on p. 109).

and Lott (1976) find that bicycle lanes are safer than none for most cases, but that there is an increased risk of crash when a cyclist turns left. Roundabouts are *most* effective at reducing just this type of crash.

Roundabouts can also be safer for bikes because cars' speed in the roundabout is closer to bike speeds, but bicyclists may be worse off if bicyclists cross the paths of drivers. Robinson et al. (2000, p. 120) note a French study that found bicyclists and pedestrians are involved in a relatively higher proportion of serious injury accidents [25 percent higher] than they are in other intersections, while personal injury crashes were twice as likely at signals. In Britain, bicyclists are more likely to be in a crash at a roundabout then at a signal. Other evidence cautions against hasty conclusions: Figure 11 shows that relative losses can be swamped by absolute gains. (They had no evidence for the United States.) European countries have therefore separated bicycles and cars in intersections with high traffic volumes (more than 8000 ADT).[16] "In the Netherlands, a 90 percent decrease in injury crashes was experienced with separate bicycle paths around roundabouts where bicyclists do not have the right-of-way crossings". (Robinson et al., 2000, p. 121)

4.2.2. *Pedestrians.* Robinson et al. (2000) say that roundabouts provide superior pedestrian safety compared to intersections with two stop

[16]For a criticism of separating bikes and cars, see Takemoto-Weerts (1998); Takemoto-Weerts notes that Davis drivers are often bikers as well, an attribute that gives us ample hope that further mixing of bikes and cars will not be as bad as pessimists predict.

Mode	All Crashes	Injury Crashes
Passenger car	63%	95%
Moped	34%	63%
Bicycle	8%	30%
Pedestrian	73%	89%
Total	51%	72%

FIGURE 11. Percentage reduction in the number of crashes by mode at 181 converted Dutch roundabouts (Robinson et al., 2000, Exhibit 5-16).

signs. The case of four-stop-sign intersections is less clear: pedestrians only have to consider one direction of traffic at a time and cars are physically slowed down by roundabouts, but roundabouts require more pedestrian judgment and caution when crossing against traffic flow, when merging drivers will be looking left instead of right. Blind pedestrians need special consideration (and are likely to get it).

4.3. **Operational Expenses and Implementation.** Compared to signals, roundabouts have lower maintenance costs, higher retrofit installation costs and similar greenfield installation costs (Lenters and Weber, 2004; Neiderhauser et al., 1997, p. 8).

Roundabouts may not work in certain locations. (See Figure 12.) Physical or geometric complications, bottlenecks which back traffic into the roundabout, unfavorable topography which may limit visibility, and heavy pedestrian or bicycle movements may not prohibit a roundabout, but they must be taken into consideration (Robinson et al., 2000, pp. 54-55).

Design Element	Mini-Roundabout	Urban Compact	Urban Single-Lane
Recommended maximum entry design speed	25 km/h (15 mph)	25 km/h (15 mph)	35 km/h (20 mph)
Maximum number of entering lanes per approach	1	1	1
Typical inscribed circle diameter[1]	13 m to 25 m (45 ft to 80 ft)	25 to 30 m (80 to 100 ft)	30 to 40 m (100 to 130 ft)
Splitter island treatment	Raised if possible, crosswalk cut if raised	Raised, with crosswalk cut	Raised, with crosswalk cut
Typical daily service volumes on 4-leg roundabout (veh/day)	10,000	15,000	20,000

1. Assumes 90-degree entries and no more than four legs.

FIGURE 12. Different roundabouts are suitable for different locations, given physical constraints and traffic flows (Robinson et al., 2000, Exhibit 1-7). A Street at 3rd has a 20 m diagonal. Richards Boulevard and Olive Drive have a 30–50 m diagonal, depending on how conservative you are with right-of-way. (There are large open spaces on a three out of four corners of the intersection.) Each of these intersections could contain a roundabout with some judicious compromises.

4.4. **Satisfaction.** Most drivers prefer a steady speed to an average speed that combines slow and fast speeds, e.g., stop and go traffic.[17] In economics, we use this preference to characterize risk aversion, i.e., that you prefer to consistently have the average payoff from a gamble instead of having to win and lose to achieve that payoff. In other words, people prefer low variation over high variation for a given average result. The

[17]Burris (2003) agrees with this, citing the number of people killed each year running red lights. He documents that drivers over-report the amount of time they are delayed in traffic (compared to reality, a similar finding to that of Berrens et al. (2004)). Overall, a majority of drivers are willing to pay something (especially if they are either rich or poor) to avoid "getting stuck" at an intersection.

intrinsic nature of a roundabout (steady, slower speeds) means that it can deliver more satisfactory results than an intersection, holding average speed constant.

Lenters and Weber (2004, p. 3) “Roundabouts are also generally preferred when considering less-quantifiable criteria such as the needs of vulnerable road users, environmental impacts from noise, fuel consumption and vehicle emissions, and aesthetics.”

Public acceptance of roundabouts has often been found the one of the biggest challenges facing a jurisdiction that is planning to install its first roundabout. Public attitude towards roundabouts improve significantly after construction (Robinson et al., 2000, p. 40).

4.5. **Community.** One benefit of a roundabout at A Street and 3^{rd} is that cars and pedestrians would cooperate more. A stop sign informs drivers that they need only stop before accelerating; a roundabout integrates them into the community—for the good of all (Engwicht, 2005; FHWA, 1994).

Lehner (1998) reports in a survey of drivers and pedestrians in Europe that pedestrians prefer that drivers be restricted while drivers prefer to be in charge. Both drivers and pedestrians agree the drivers speed to save time or because they are in a hurry, but drivers are alone in saying that they speed “because there is little traffic.” (A reflection of different attitudes towards a roads *qua* dividers or unifiers of points of interest.) Roundabouts reduce speeds while allowing drivers to stay in charge.

Redmon (2003) reports that pedestrians feared being hit by cars while drivers fear law-enforcement. Drivers said "they did not want to hurt pedestrians, but they also did not want them in their way" [p 28]. While this report suggests that driver/pedestrian interaction needs to improve, the author, a transportation specialist in the Federal Highway Administration's safety office, suggests greater awareness and enforcement of laws. This solution is no surprise, coming from someone whose job is command-and-control, but the fact is the drivers rarely pay attention to posted signs (Francisco, 2005). A more productive route may be to make them think more, not less, about their relationship to pedestrians (e.g., as Monderman suggests in Lyall (2005). See also Appendix—"Livable Streets."). As many psychologists have suggested (e.g., Axelrod and Hamilton (1981); Berg et al. (1995); Fehr and Fischbacher (2002); Fehr and Schmidt (1999)), community feelings are not hard to invoke—they underly millennia of social cooperation.

5. Evaluating The Consequences of Alternatives

To evaluate the alternatives, I reviewed (some of) the extensive literature on roundabouts, congestion, and driver attitudes; gathered statistical information on my two intersections; and spoke with a City of Davis Traffic Planner to understand current thinking in their department.

Accounting Stance: Residents and commuters in the city of Davis. (Traffic-control is a local matter. Although there are federal standards for traffic control symbols.)

Benefits: As discussed in Section 3.1, benefits are measured in traffic flow (delay), safety, and quality of life.

Costs: Installation and operating costs are quantifiable.

Justification: Traffic-control is often analyzed using benefit-cost analysis. For the sake of comparison, I will continue in that tradition, but I will also examine the qualitative differences between the alternatives, as their significant impact may change the eventual recommended action.[18]

Sensitivity Analysis: The most obvious target for sensitivity analysis is the impact on safety. Some say that safety is not quantifiable *per se*.[19] For this reason, I will measure safety in nominal (absolute numbers) and converted (monetary) terms.

As shown in Table 3, Roundabouts have an annual advantage of $267,000. This must be compared to the operations disadvantage (over

[18]For a long time, quality-of-life and efficiency of traffic flow were separated in people's minds, but "radicals" such as Engwicht and Monderman have brought them together in one debate called "living in a community." Both are advocates of reintegrating drivers into the space they traverse and building interaction between drivers, pedestrians, bicyclists and residents to restore the social fabric that gives life meaning.

[19]Hauer (1994) questions whether or not life can be valued at all in cost-benefit analysis. If an increased traffic flow (decreased delay) leads to more fatalities, can we actually balance cost to benefit? Traffic calming, including roundabouts, slows down traffic, increases safety and *reduces* efficiency, but it also contributes to qualitative improvements in life when the car shares the road with bicyclists and pedestrians. These qualitative improvements are often omitted from cost-benefit analysis"because bureaucracies, professions and professionals have a vital interest and continued acceptance of decision by computation" (Hauer, 1994, p 115).

Table 3. Construction cost for the signal is zero in the first year, since it is already in place. The $350,000 construction cost may be high; signalization in Davis cost $180,000 in 1996 (Pelz and Flecker, 1996). Richards Blvd/Olive Drive accident statistics for 2000-2004 (DPD, 2005). 100% accident reduction is from the literature; 25% reduction/increase is my interpretation of the literature. "Other" includes bicycle, object and single-vehicle accidents. I assume bicycle accidents cost $80,000/each (1996 dollars) and object/single-vehicle accidents cost $20,000/each. Other rises because I assume (conservatively) that the roundabout makes no provision for bicycle/car separation. Delay savings use 5,000/vehicle-hrs/year at $10/hr from Figure 8.

	Signal	Roundabout
Quantitative Differences		
Operations		
Construction Cost	$100,000	$350,000
Maintenance Cost	$6,500	$1,000
Project Life	10 years	25 years
Total Cost (NPV, 5%)	$176,000	$364,000
Difference (25 Year base)		+$188,000
Accidents		
Rear-Ender	5	3.75 (-25%)
Broadside/Head-on	1.6	0 (-100%)
Other	2	2.5 (+25%)
Accident Costs		
Rear-Ender	$370,000	$277,500
Broadside/Head-on	$149,600	$0
Other	$100,000	$125,000
Total Cost (annual, PV)	$619,600	$402,500
Annual Difference	+$217,100	
Annual Delay Savings	$0	($50,000)
Qualitative Differences		
Speed—Mean	−	+
Speed—Variance	−	+
Inclusion	−	+
Security	−	+

a *total of 25-years*) of $188,000 in current dollars. Thus, a roundabout at Richards and Olive would have roughly a 35:1 advantage over the current signal. If we include the qualitative advantages, a roundabout looks even better.[20]

The case for A Street at 3^{rd} is more subtle. Since there are very few accidents at this intersection right now, (two in the last five years with no injuries, according to DPD (2005).) a case must be made for other benefits, which can be measured against smaller costs (since a mini-roundabout costs about $10,000 to install).[21] Currently, bicyclists ignore the stop sign at this intersection and cars wait as long as bikes are passing before leaving (effectively a yield sign). There are, however, many instances of "coordination problems" where a bike and car will simultaneously go, thinking that the other is going to stop. This problem results in many near collisions and can be addressed with a mini roundabout (between five and ten meters in diameter, the intersection diagonal is about 20 m.), which would improve users' satisfaction.

6. Uncertainty and Risk

6.1. **Major Sources of Uncertainty.**

[20] These numbers may seem overly-optimistic. Doubling the construction cost to $700,000 may reduce them to a 17:1 advantage. Accident costs are likely to be understated; they are in 1996 dollars from a study of accidents that took place between 1990-93 in Maryland, which *may* have a lower population/capita of personal injury lawyers.

[21] In 1996, they cost about $6,000 in Seattle (FHWA, 1994). The temporary roundabout installed at Alvarado and Anderson cost $18,000; The permanent configuration was $40,000 (Pelz and Flecker, 1996).

- Driver reactions to roundabouts are sometimes a surprise, either good or bad. FHWA (1994, p. 52) reports that businesses, media and policy makers often underestimate public support for traffic-calming; this evidence should be used to counter overly-pessimistic reactions from policy-makers that roundabouts won't work.
- Safety may not materialize as soon as expected or according the averages. A fatality from a disoriented driver at a new roundabout could kill public support.
- The network effects of altering traffic flow are sometimes uncertain. In my 212B presentation, someone mentioned that traffic may backup from the stoplight at Richards and 1^{st} Street. This would halt movement in the roundabout. There are two solutions to this: install another roundabout at Richards and 1^{st} Street or put a signal south of the roundabout that prevents northbound traffic from entering the roundabout if the traffic backs up.
- It may be impossible to buy the right-of-way from land-owners at the corners of any roundabout location. This can stop the project—unless bribery or eminent domain changed the outcome.

6.2. **How Alternatives Change Risk.** My single feasible alternative (roundabouts) reduces the risk of passing through an intersection. Lower average speeds give everyone more time to react and interact. The design also creates a necessity of interacting with other roundabout-goers, increasing the risk of actual eye-to-eye (not bumper) contact. The risk for those unfamiliar with roundabouts is negative, but this risk is not much different from any *new* situation. People manage to jay-walk all over the place (blind people may be one exception, but they are likely to be assisted or accommodated across the intersection). There is a risk that people will not behave respectably in the intersection, but I have faith that they will be nice. (So do Axelrod and Hamilton (1981); Berg et al. (1995); Cummins (2004); Engwicht (2005); Fehr and Fischbacher (2002); Fehr and Schmidt (1999); Leikanger (2005); Lyall (2005).)

7. Recommendation

I recommend that the Davis City Council proceed to investigate the feasibility of converting Richards Boulevard and Olive (A Street and 3^{rd}) from signal (stop sign) to urban-single-lane (mini) roundabout.

8. Further Research

To strengthen my problem definition, systems description and multi-criteria analysis, I need to do the following:

(1) Survey Davis commuters, residents, and police on their attitudes towards the subject intersections.
(2) Update statistics (ADT, accident costs, etc.).
(3) Discuss the technical/engineering potential of change at the two intersections. Get cost (time and money) estimates for change.
(4) Discuss the political potential for change with the City Council (and UC administration, at A and 3^{rd}).

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Appendix: Livable Streets

His challenge to rational traffic planning principles? Remove the signs and traffic-control lights. That is lateral thinking of the highest order. No wonder he was laughed at for a long time. That always happens whenever someone challenges an established, basic assumption. This is that basic assumption: Cars are made to move people from A to B—their quick and efficient movement has priority—signs and traffic controls and multi-lane roads ensure the quick and efficient movement of cars.

However, Monderman wasn't seeing quick and efficient motion, he was seeing stop/go/slow-down/speed-up/stop.

Think of whenever you've stopped for a red light, in the middle of the night, in a city. No cars in front of you, no cars behind, no cars to either side of you. And you're drumming away time as you are waiting for the light to change from red to green. Monderman was seeing variations of that all day: enforced pauses where there was no need for them. He posited that congestion, traffic jams and rush-hour could be alleviated if not eliminated by taking away enforced flow-control. He also stated that traffic should be slowed down, in order to have it be able to move quicker. (Another wonderful lateral insight). The trouble was that traffic was moving so fast that people didn't dare interact with cars unless the river of cars was stopped by a red light. By slowing down traffic, cars and pedestrians could interact.

Leave the control to the people using the roads, he said, both drivers and pedestrians. They'll know what to do, they'll be able to sort out their priorities efficiently. The present system where management results from laws, regulations and police supervision has people disassociating themselves from what is happening outside the car, and leads to drivers not seeing the people they are driving past. By removing the regulatory cues, signs and controls, drivers are reminded that they are part of the environment they are in, and not just passing through. Monderman wanted to manipulate the lay-out of roads, the surrounding architecture and the width of

> roads, to regulate speed where slower speeds were required.
>
> Monderman was told he was crazy, and that his ideas would increase traffic accidents between people and cars. But he was allowed to conduct a few trials, in the Netherlands. The results have revolutionized traffic control, and have also reduced traffic fatalities significantly. (Leikanger, 2005)

Monderman's "sign free" intersections are similar to those in Davis (20,000 ADT). Although the United States is different from the Netherlands in many respects, Davis should be able to handle the complexities of an "interactive" intersection. As Monderman says,"They are treating you like your complete idiot, and if people treat you like a complete idiot, you will act like one" (Lyall, 2005).

For more on livable communities where cars and people cooperate, see Engwicht (2003).