EVALUATION OF AN ALTERNATIVE, UNIQUE INTERSECTION SCHEME: THE CONTINUOUS TURBO INTERSECTION

Peter Yu
Junior, Pullman High School
Pullman, WA 99163
Email: peteryu0822@gmail.com

Abstract

Traffic growth and outdated transportation infrastructure have resulted in increased congestion and delays on arterial roadways. Wasted fuel and time continue to increase as signalized intersections become more congested. Thus, the demand for new roadway and intersection design is a high priority. This paper presents a new intersection scheme, the continuous turbo intersection (CTI). Its design allows one direction of the major highway to flow continuously without ever having to stop, while still providing benefits for left-turning traffic and minor road through traffic in a four-legged intersection. VISSIM is used to model and compare the CTI with a conventional intersection. The analysis demonstrates significant improvements over conventional intersection design, particularly for higher entering volumes. Substantial benefits are observed for the CTI in terms of delay, travel times, speed, stops, throughput, fuel consumption, and emissions of carbon monoxide and oxides of nitrogen. Additionally, an economic analysis shows significant user savings associated with the CTI. These findings strongly demonstrate the design's viability at congested intersections in suburban areas where space is available.

Introduction

Growth of vehicular travel demand and aging transportation infrastructure has led to severe congestion and decreased travel efficiency on principal arterial roadways. This is especially true at signalized intersections, where motorists primarily face recurring congestion problems. Intersections with particularly high left-turning volumes combined with heavy through volumes are of particular concern, as it then becomes difficult to allocate adequate green time to provide sufficient capacity for the left-turning vehicles (Polus and Cohen 1997). Conversely, too much time is often devoted to left turns, impeding both through traffic and traffic on the minor road. Since left turns have a significant impact on the operational performance of intersections, much of the poor performance at signalized intersections can be attributed to the existence of one or more left-turn-opposing conflicts (Tabernero and Sayed 2006). Consequently, many existing intersections are oversaturated and unable to adequately handle current traffic demands, creating both operational and safety problems.

While finding appropriate approaches to reducing traffic congestion and improving mobility on arterial roadways is an important task, financial constraints and other factors have made it increasingly difficult to make corrective, significant modifications to these facilities. Therefore, transportation practitioners have turned to less conventional intersection designs to improve traffic operations and safety at highway junctions. These designs remove one or more critical conflicting left-turn movements from the main intersection, which can result in shorter delays and increased capacities when compared to conventional intersections (Hughes et al. 2010). Examples of alternative intersections include the median U-turn, superstreet, quadrant roadway intersection, and continuous flow intersection (Reid and Hummer 2001).

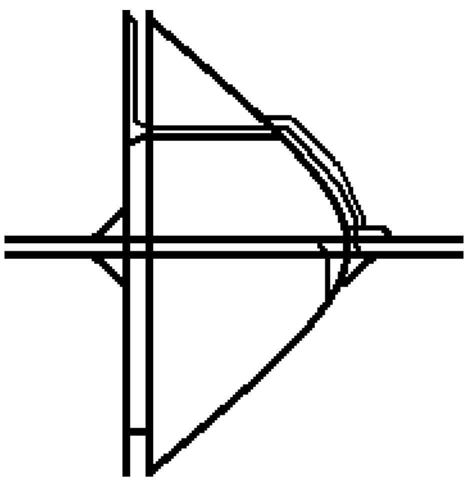
Another alternative intersection design that has been used for many years in Florida and various other states (Reid 2004; Hughes et al. 2010) is the continuous green-T (CGT) intersection. CGT intersections provide free-flow operations in one direction of the main through-roadway and free that particular direction from having to stop. As a result, delay, fuel consumption, and emissions are all considerably reduced in comparison to conventional signalized T-intersections (Litsas and Rakha 2013). CGT intersections can also be more easily integrated into progressive traffic signal systems (Reid 2004). Although the CGT Intersection significantly improves operations for at least one direction of travel on the major arterial, it is only applicable at intersections with three approaches. It is also disadvantaged by the lack of a protected (signalized) pedestrian crossing of the major arterial (Reid 2004).

This paper introduces and examines a new, at-grade intersection configuration titled the "continuous turbo intersection" (CTI). The idea behind the CTI's design is to allow continuous through movement in one direction of the major roadway without the use of grade separation, while still providing benefits for left-turning traffic and minor road through traffic in a four-legged intersection. By splitting one direction of the major roadway into two through paths and spacing the traffic signals appropriately, the signal timings can be set so that through movements in that particular direction always have a choice for a green phase through the intersection. The signal timing, traffic control, and traffic negotiation strategies must exist such that the through vehicles are able to correctly select which path to travel at the split to effectively get green lights. Through a strategic consideration of signal timing and geometric design, one of the two through paths is guaranteed to have green lights.

The primary contribution of this paper is the implementation of a free-flow through movement at a four-leg signalized intersection for the first time. Traffic patterns and operations, signal phasing, and geometric design are detailed. Next, operational and sustainability characteristics of the CTI are analyzed through microscopic traffic simulation. Simulation results are aggregated and compared between the CTI and a conventional intersection. Microsimulation case networks and modeling parameters that are used in the analysis are then described. Lastly, results are presented and discussed.

Continuous Turbo Intersection

The focus of this paper is to discuss a new and unconventional intersection configuration, which has been given the name "continuous turbo intersection." Figure 1 illustrates a schematic of this intersection.



Design of a continuous turbo intersection

Left turns from one direction of the major roadway and one direction of the minor roadway are made at two additional intersections located several hundred feet from the main intersection. This is similar to how major road left turns are made in a jughandle intersection, but with traffic signals instead of stop signs (Reid and Hummer 2001). The other two left-turn movements are handled by a median U-turn crossover on the major roadway. When this is applied to a four-legged intersection, all left-turning traffic is eliminated from the main intersection, which simplifies signal operations at the intersection and accounts for many of the benefits. Moreover, as one direction of travel on the major roadway never stops, higher traffic loads are allowed and arterial travel times are reduced.

Traffic Patterns

Traffic flow patterns for the CTI are described below. For ease of explanation, this paper assumes that up is north and that the main intersection is always to the west. The directions in the following descriptions are an arbitrary set of cardinal directions, provided only for explanatory purposes.

Northbound traffic splits into two through paths prior to both the main intersection and median U-turn crossover; one of the paths is guaranteed to have green lights through the intersection. The traffic that splits to the right has one signalized intersection at a secondary intersection several hundred feet to the east of the main intersection. The traffic that splits to the left has three signalized intersections: one at the median U-turn crossover, one at the main intersection, and one at an additional intersection several hundred feet downstream of the main intersection. Northbound traffic then merges back to one flow of traffic downstream of the signalized intersections. At the split for northbound traffic, all traffic that wishes to turn onto the minor road takes the split to the right in order to arrive at a secondary intersection, where both left turns and right turns are made. Left-turning traffic travels through the main intersection after turning onto the minor road. Right turns may or may not be free-flow.

Signal Description

Six traffic signals are needed for this design, one at each of the five intersections and at the merge of the two northbound roadways. Each traffic signal is two-phased. In the first signal phase, all southbound and northbound traffic proceeds simultaneously, with northbound traffic taking the left split. Eastbound and westbound traffic are stopped at the main intersection, but proceed at the next signal. All left turning traffic is stopped, while right turns from southbound and westbound traffic proceed. The second signal phase stops southbound through traffic but allows northbound traffic to proceed by taking the right split. Eastbound and westbound traffic are now stopped, but proceed at the next signal. All left turning traffic may proceed in this phase; right turns from northbound and eastbound traffic proceed. The signals are synchronized, phased, and timed in a way to ensure that no northbound through traffic has to stop anywhere in the intersection.

Benefits

A primary benefit of the CTI in comparison to conventional intersections designs is that it only requires a two-phase traffic signal to operate, unlike four phases found in conventional intersections. As described earlier, the most influential factor in an intersection's performance for heavy flows is the number of signal phases per cycle. Because left-turning traffic in a CTI has been eliminated from the main intersection, one or more phases can be eliminated. This in turn creates shorter cycle lengths, meaning that there can be more cycles per hour. As such, delays throughout the intersection are substantially reduced, and the safety and capacity of the intersection are both increased.

One remarkable advantage of the CTI over conventional intersection designs is that a much higher number of through movements on the cross road can be accommodated. The ability to accommodate a heavy amount of through movements, along with a two-phase traffic signal, greatly improves both the efficiency and capacity of the intersection. Construction costs for a CTI are also substantially reduced in comparison to a grade-separated interchange, as no grade separation is involved.

Limitations

Although the advantages of the CTI make it an excellent solution for a variety of situations, it is not applicable everywhere. Like any other engineering solution, there are limitations that must be considered. The three potential limitations of a CTI are: (a) Greater right-of-way needs. (b) Potential increases in stops and delays for left-turning traffic and minor road through traffic. (c) Possibility for driver confusion. Nevertheless, a CTI costs significantly less than an interchange and right-of-way may be comparable. The benefits from a two-phase signal and "free-flow" movement generally outweigh the disadvantages of higher stops and delays for left-turning traffic and minor road through traffic, and careful signing, pavement markings, and geometric design reduce confusion and errors.

Methods

The traffic simulation software VISSIM is used to gain insight into the operational performance of the CTI in comparison to the conventional intersection. VISSIM is one of the most preferred methods for analyzing intersections and interchanges. One geometric design case of each intersection was simulated under six different traffic scenarios. The intersections simulated involved two four-lane highways with dual left-turn lanes and one right-turn lane on each approach; the lane configurations and geometric features for all intersections were similar. The vehicular volumes were balanced on opposing approaches (50/50 directional split).
The following assumptions were employed in the VISSIM model for each of the simulated scenarios:

- Optimum fixed signal timing determined using Synchro for the conventional intersection, manually for the CTI.
- Yellow change intervals and red clearance intervals determined using ITE guidelines.
- Total of 5% heavy vehicles on all legs.
- Study boundary (network size) of 1 mile in each direction from the main intersection.
- Right turn on red allowed, no left turn on red.
- Desired speed of 45 mph on major road.
- Desired speed of 35 mph on minor road.
- Simulation period of 4,800 s (1,200 s warm-up period, 3,600 s of data collection)

Results

All of the test configurations and results are shown in the tables below.

Continuous Turbo Intersection (4-Lane) vs. Conventional Intersection
Traffic Scenarios and Performance Results

Traffic Scenario	Total Volume (vehicles/hour)	Major Road Volume Per Direction (vehicles/hour)	Minor Road Volume Per Direction (vehicles/hour)	Through/Left/Right Percentages (%)
High 4	9,800	2,800	2,100	60/30/10
High 3	8,400	2,400	1,800	60/30/10
High 2	7,000	2,000	1,500	60/30/10
High 1	5,600	1,600	1,200	60/30/10
Medium	4,200	1,200	900	60/30/10
Low	2,800	800	600	60/30/10

Traffic Scenario	Intersection Design	Throughput (vehicles/hour)	Total Travel Time (veh–hours)	Total Delay (veh–hours)	Total Number of Stops (#)
High 4	Conventional CTI Improvement	6,960 9,728 28%	1,410 889 37%	1,047 526 50%	48,389 24,712 49%

High 3	Conventional	6,959	1,244	878	42,120
	CTI	8,376	627	258	11,207
	Improvement	20%	50%	71%	73%
High 2	Conventional	6,780	667	313	15,976
	CTI	6,991	398	38	6,453
	Improvement	3%	40%	88%	60%
High 1	Conventional	5,588	357	69	4,608
	CTI	5,608	314	26	2,378
	Improvement	0%	12%	62%	48%
Medium	Conventional	4,181	252	37	3,240
	CTI	4,153	231	17	1,674
	Improvement	–1%	8%	54%	48%
Low	Conventional	2,791	162	20	2,037
	CTI	2,775	152	9	1,055
	Improvement	–1%	6%	55%	48%

Traffic Scenario	Intersection Design	CO Emissions (grams)	NO_x Emissions (grams)	Fuel Usage (gallons)
High 4	Conventional	112,934	21,973	1,616
	CTI	58,033	11,291	830
	Improvement	49%	49%	49%
High 3	Conventional	103,402	20,188	1,479
	CTI	48,249	9,388	690
	Improvement	53%	53%	53%
High 2	Conventional	60,422	11,756	864
	CTI	39,762	7,736	568
	Improvement	34%	34%	34%
High 1	Conventional	35,011	6,812	501
	CTI	31,495	6,128	451
	Improvement	10%	10%	10%
Medium	Conventional	25,401	4,942	363
	CTI	23,352	4,543	334
	Improvement	8%	8%	8%
Low	Conventional	16,521	3,214	236
	CTI	15,406	2,997	220
	Improvement	7%	7%	7%

Economic Analysis

A simple economic analysis provides encouraging documentation of substantial benefits when converting to the CTI. The computed results show the extent of savings per year in vehicle-hours and in equivalent costs. The assumptions used in the computations are as follows:

- Four hours of peak periods per day (*h*).
- Peak period occurs over 250 working days per year.
- Nationwide average occupancy factor of 1.6 passengers per vehicle (*p*).
- Recommended hourly value of travel-time savings per person-hour of $19.69 (*c*).

$C = (q)(h)(250)(d/3600)(p)(c)$

C = Estimated annual total cost ($/year)

q = Peak volume (vph)

d = Average savings in delay (seconds/veh)

Traffic Scenario	Delay Savings Per Year (hours)	Fuel Savings Per Year (gallon)	CO, NO_x Reduction (tons)	Cost Savings Per Year ($)
High 4	521,000	786,000	61, 12	16,414,000
High 3	620,000	789,000	61, 12	19,532,000
High 2	275,000	296,000	23, 4	8,664,000
High 1	43,000	50,000	4, 1	1,355,000
Medium	20,000	29,000	2, 1	630,000
Low	11,000	16,000	1, 1	346,000

Conclusions

This study examines a new design to accommodate common heavy traffic patterns that conventional intersections are insufficiently managing. The author develops the continuous turbo intersection as a new way to provide higher efficiency and capacity, along with increasing safety for all users and reducing the cost of construction.

As with all other intersection designs, the CTI is applicable under certain conditions; one main reason to choose the CTI is the two-phase signal operation, which allows higher efficiency and capacity. For higher traffic volume conditions, the CTI has much better performance and offers much lower delays as compared to the performance of the conventional intersection. For low volumes, the performances of the CTI and conventional intersection are relatively similar. As compared to the conventional intersection, capacity for all signalized movements is higher for the CTI.

CTI intersections are best suited under these conditions:

- Heavy through volumes on the major road.
- Moderate volumes from the minor road.
- Moderate to heavy left-turning volumes.
- Sufficient right-of-way is available.

References

Bared, J.G., and Kaisar, E.I. (2000). "Benefits of Split Intersections." *Transp. Res. Rec.*, 1737, 34–41.

Hughes, W., Jagannathan, R., Sengupta, D., and Hummer, J. (2010). "Alternative Intersections/Interchanges: Informational Report (AIIR)." *Publication No. FHWA-HRT-09-060*, Federal Highway Administration, McLean, VA.

Polus, A., and Cohen, R. (1997). "Operational Impact of Split Intersections." *Transp. Res. Rec.*, 1579, 73–78.

Reid, J.D., and Hummer, J.E. (2001). "Travel Time Comparisons Between Seven Unconventional Arterial Intersection Designs." *Transp. Res. Rec.*, 1751, 56–66.

Tabernero, V., and Sayed, T. (2006). "Upstream Signalized Crossover Intersection: An Unconventional Intersection Scheme." *J. Transp. Eng.*, 10.1061/(ASCE)0733-947X(2006)132:11(907), 907-911.