Operational Performance Assessment of innovative High Speed Urban Arterial Intersections – A Case Study in Salt Lake City, UT

M. Scott Shea[a], Kevin Croshaw[b]

[a]Department of Civil and Environmental Engineering, University of Utah, 110 Central Campus Dr, Ste 2000, Salt Lake City, UT 84112

[b]Horrocks Engineers, 2162 W Grove Pkwy #400, Pleasant Grove, UT 84062

Introduction

Intersections are being pushed to capacity as urban development expands and standard improvements cannot improve capacity indefinitely. Traffic engineers look for innovative solutions to increase intersection capacity. Identifying a "one-size-fits-all" solution to address all intersection types is unlikely; adequate assessment of intersections requires an individualistic approach. State department of transportation (DOT) agencies have additional constraints in identifying a preferred alternative, including: operations, right-of-way (ROW), funding, and construction management of traffic (MOT).

This research develops a comparative technique for selecting a preferred alternative for intersection improvements. Arriving at a preferred alternative is best displayed through a case study. Bangerter Highway (SR-154) and Redwood Road (SR-68) intersect in Salt Lake City, UT as an at-grade multilane intersection (Figure 1). Bangerter Highway is an urban belt route with heavy AM eastbound and PM westbound traffic. Redwood Road is a major north and south arterial. Roadway volumes are near capacity and the 2040 outlook indicates a failing level-of-service (LOS). Table 1 outlines the roadway geometry.

For this case study, there four alternatives were analyzed: 1) standard intersection improvements, 2) a continuous flow intersection (CFI), 3) a single point urban interchange (SPUI), and 4) a diverging diamond interchange (DDI). An intersection rating is provided to minimize cost, ROW impact, and meet LOS criteria. Arriving at a preferred alternative is best displayed through a case study.

Figure 1: Intersection of east-west Bangerter Highway (SR-154) and north-south Redwood Road (SR-68) in Salt Lake City, UT.

Table 1: Intersection Geometry

Approach		Left Turn Operation	Left Turn Lanes	Through Lanes	Right Turn Lanes
Redwood Rd (SR-68)	NB	Perm / Prot	1	2	2
	SB	Perm / Prot	1	2	1
Bangerter Highway (SR-154)	EB	Protected	2	3	1
	WB	Protected	2	3	1

Literature Review

Several comparisons have been performed indicating effective intersection types. UDOT published a white paper for Continuous Flow Intersections (CFIs), indicating a CFI can be considered when volumes are below 70% of free flow lane capacity[1]. Bonneson and Lee compare the operational benefits of interchange types using critical-movement analysis (CMA)[2]. Selinger and Sharp compare the SPUI with a tight urban diamond interchange (TUDI) with a frontage road system[3]. They conclude the SPUI provides greater operational benefits but construction costs may outweigh the benefits. Pate and Stover argue the TUDI and SPUI require the same ROW footprint[8]. Kane et al. replace a signalized intersection with a flyover interchange design for the main traffic movement[4]. Kaisar compares signalized and un-signalized roundabouts, a CFI, and a Parallel Flow Intersection (PFI) at various traffic volumes[5]. Fowler uses lane configuration and volume counts to increase effectiveness of a TUDI[7].

Data and Methods

VISSIM was used for modeling. Signal spacing is greater than a mile for three approaches allowing for random vehicle arrival on those approaches and does not require a system model of intersections. Each model used in this analysis includes signalized intersections along Redwood Road at 13400 South, Bangerter Highway, and 14400 South. Signal timings were obtained from the UDOT traffic operations center and traffic volumes from the UDOT database. The existing model was calibrated by comparing the model volumes to the UDOT database volumes using ten simulations, provided in Table 2. The existing conditions model serves more than 94% of traffic volumes of each movement and 100% of the total volume with an R^2 value of 0.999. Travel times on Redwood Road were obtained Thursday, November 14, 2013, during the PM peak period using four travel runs. Average travel times were 2:21 northbound and 2:03 southbound (Table 3). Two segments in the model show longer travel times than actual travel times which may be due to random vehicle arrival in VISSIM as platooned cars separate and become more random. The R^2 is 0.933, indicating a validated model. After validation, traffic volumes were grown at 2% according to the Wasatch Front Regional Council (WFRC) for the 2040 design and each geometric modification was completed.

Table 2: Calibrating Traffic Volumes with Existing Model and Operations

Movement		Modeled Vehicles	Traffic Volumes	% Modeled	Vehicle Difference	Delay (sec) / LOS	2040 Volumes
EB	Left	236	250	94%	-14	67 / E	400
	Thru	942	898	105%	44	47 / D	1440
	Right	248	250	99%	-2	10 / A	400
WB	Left	494	495	100%	-1	55 / D	800
	Thru	1672	1634	102%	38	37 / D	2620
	Right	216	222	97%	-6	12 / B	360
NB	Left	228	227	101%	1	39 / D	370
	Thru	283	288	98%	-5	46 / D	470
	Right	281	276	102%	5	10 / A	450
SB	Left	105	106	99%	-1	33 / C	170
	Thru	324	331	98%	-7	53 / D	530
	Right	54	52	103%	2	9 / A	90
Intersection		5082	5029	101%	53	39.4 / D	8100

Table 3: Model Validation to Travel Times Runs

Travel Time (sec)	13400 South to Bangerter (SB)	Bangerter to 14400 South (SB)	14400 South to Bangerter (NB)	Bangerter to 13400 South (NB)
Model	86.8	69.1	92.5	49.7
Actual	78	69	77	50
Difference	8.8	0.1	15.5	0.4

Results and Analysis

The model for each alternative was calibrated using ten simulations and the results were analyzed. Intersection LOS analysis is performed using a weighted average total vehicle delay from the Highway Capacity Manual (HCM)[9]. UDOT requires a minimum LOS C for peak period designs.

The future (No Build) model shows the intersection is inadequate to handle the demand serving the westbound through, left, and right movements only 87, 87 and 84 percent of the given volumes, respectively. Tables 4-6 provide the vehicle delay, queue length, and capacity (V/C) analysis for the existing model and the future no build, CFI, DDI, and SPUI alternatives, respectively. Table 6 replaces the no build with typical improvements of adding additional lanes to increase capacity. Average vehicle delay for the no build and CFI options are below the LOS C minimum criteria, thus eliminating the alternative as an option. Maximum queue lengths also exceed 1,000 feet, making the no build and CFI options impractical. Typical improvements of adding lanes and optimizing signal timing improve the V/C ratio and LOS but do not provide adequate improvement to be considered. The V/C of the DDI is much improved due to the capacity requirement to become 3 through lanes, which increases the cost and complicating driver expectancy. Table 7 provides an intersection rating guide using a scale of 1 to 10 with 1 as the best option and 10 the least option based on analysis, experience, and engineering judgment as assigned by the DOT and designing engineer.

Table 4: Vehicle Delay (sec) / LOS for No Build, CFI, DDI, and SPUI Models

Movement		Existing	No Build	CFI	DDI	SPUI
EB	Left	67 / E	61 / E	83 / F	13 / B	42 / D
	Thru	47 / D	108 / F	32 / C	0 / A	1 / A
	Right	10 / A	27 / C	23 / C	8 / A	24 / C
WB	Left	55 / D	58 / E	85 / F	20 / B	46 / D
	Thru	37 / D	146 / F	44 / D	0 / A	2 / A
	Right	12 / B	29 / C	15 / B	11 / B	19 / B
NB	Left	39 / D	57 / E	76 / E	33 / C	44 / D
	Thru	46 / D	45 / D	39 / D	33 / C	22 / B
	Right	10 / A	15 / B	9 / A	9 / A	7 / A
SB	Left	33 / C	73 / E	93 / F	24 / C	59 / E
	Thru	53 / D	71 / E	44 / D	32 / C	37 / D
	Right	9 / A	46 / D	12 / B	11 / B	11 / B
Intersection		39.3 / D	65.9 / E	45.5 / D	13.1 / B	16.8 / B

Table 5: Avg. / Max Queue Length (ft) for No Build, CFI, DDI, and SPUI Models

Movement		Existing	No Build	CFI	DDI	SPUI
EB	Left	55 / 195	74 / 402	89 / 372	10 / 87	67 / 281
	Thru	92 / 344	332 / 1138	88 / 415	0 / 0	0 / 0
	Right	12 / 176	47 / 444	0 / 53	0 / 0	43 / 251
WB	Left	85 / 322	190 / 670	152 / 496	19 / 124	118 / 517
	Thru	125 / 582	195 / 435	273 / 1092	0 / 0	0 / 0
	Right	9 / 125	57 / 384	0 / 0	39 / 480	110 / 519
NB	Left	52 / 330	97 / 423	91 / 361	43 / 332	51 / 297
	Thru	43 / 198	38 / 236	49 / 291	43 / 332	29 / 213
	Right	10 / 95	33725	25934	1 / 117	8 / 207
SB	Left	18 / 147	1097 / 1674	53 / 176	22 / 171	33 / 142
	Thru	56 / 226	136 / 956	64 / 285	22 / 171	61 / 297
	Right	2 / 67	51 / 318	0 / 0	0 / 0	4 / 101
Intersection		79 / 359	425 / 916	136 / 557	24 / 261	44 / 519

Table 6: Capacity (V/C) / LOS for Typical Improvements, CFI, DDI, and SPUI Models

Movement		Existing	Typical Improvements	CFI	DDI	SPUI
EB	Left	1.20 / F	0.80 / E	1.20 / F	0.26 / A	0.49 / C
	Thru	0.88 / D	0.66 / D	0.90 / D	0.46 / A	0.46 / A
	Right	0.37 / C	.37 / C	.37 / C	0.38 / B	0.68 / D
WB	Left	0.84 / D	0.56 / D	1.37 / F	0.51 / B	0.98 / E
	Thru	1.03 / E	0.77 / C	1.63 / F	0.84 / A	0.84 / A
	Right	0.21 / B	0.21 / B	0.34 / C	0.34 / B	0.61 / D
NB	Left	2.17 / F	1.09 / F	1.16 / F	0.71 / B	0.63 / D
	Thru	0.47 / D	0.32 / C	1.30 / F	0.30 / A	0.44 / B
	Right	0.23 / C	0.23 / C	0.11 / A	0.43 / B	0.21 / B
SB	Left	0.61 / E	0.30 / D	0.94 / F	0.33 / B	0.81 / E
	Thru	0.70 / D	0.47 / D	1.12 / F	0.34 / A	0.78 / D
	Right	0.11 / D	0.11 / D	0.04 / A	0.09 / A	0.13 / C
Intersection		E	D	F	A	C

Table 7*:* Rating Guide Comparison of Alternative Intersections

Alternative	**ROW**	**Construction Cost**	**Operations**	**Safety**	**Pedestrian / Bicycle Consideration**	**Driver Expectation**	**Total**
No Build	1	1	10*	1	1	1	15*
Standard Improvement	1	4	7*	1	1	1	15*
CFI	5	5	8*	5	5	3	31*
SPUI	5	8	3	3	3	2	24
DDI	5	6	1	5	7	4	28

*Indicate inadequate LOS and cannot be recommended

Discussion and Conclusion

The DDI and SPUI options both provide a reliable alternative meeting delay, queuing, and capacity analysis. Consideration for ROW acquisition, construction costs, safety, and user expectation is required to determine a preferred alternative. The SPUI provides better consideration and safety to pedestrians and bicyclists, as well as providing a better driver expectancy in maneuvering through the intersection. The SPUI alternative provides the best rating while meeting all design requirements.

Constructing a grade-separated SPUI intersection improves the 2040 vehicle delay to LOS B. The design SPUI provided dual left turn lanes, however, triple left turns would provide greater capacity and improved LOS if built immediately or in the future. The reduction in delay from the future no build to the SPUI interchange is approximately 49.1 seconds per vehicle. Using a value of time (calculated as the average wage in the state per UDOT research and development team) as $21.00/hr., the SPUI interchange results in 8,100 vehicles saving 49.1 seconds during the peak period. The calculated average savings will be $2,320 per peak period and when using a 250 workday year, a yearly savings of $1,160,000. Project costs will be saved over the life of the improvements as the 2040 lifespan of the SPUI saves $34.8million during peak periods alone. The calculated total value for this project is $44.5million as assessed by UDOT. With a preferred alternative, additional analysis for the AM peak period can be verified quickly using the proposed design and additional traffic volume and travel times.

This project analyzed movement and intersection delay (LOS), queue length, and capacity (V/C) for each alternative, and determined a SPUI intersection as the preferred alternative.

References

[1] "CFI Guideline - A UDOT Guide to Continuous Flow Intersections," July 2013, unpublished|.

[2] J. A. Bonneson and S. Lee, "Technique for comparing operation of alternative interchange types," *Transportation Research Record: Journal of the Transportation Research Board,* vol. 1802, pp. 7-15, 2002.

[3] M. Selinger and W. Sharp, "Comparison of SPUI and TUDI interchange alternatives with computer simulation modeling," *Institute of Transportation Engineers,* 2000.

[4] M. R. Kane, C. M. Kone, and W. A. Eagle, "Signal Replacement with an Interchange," 2007.

[5] E. I. Kaisar, P. Edara, J. D. Rodriguez-Seda, and S. Cherry, "A Comparison of Non-traditional Intersection Designs Using Microscopic Simulation," in *Transportation Research Board 90th Annual Meeting*, 2011.

[6] S. Vadaei, "Impacts of Replacing a Tight Diamond Interchange with a SPUI–A Wilsonville Interchange Study," 2015.

[7] B. Fowler, "An operational comparison of the single-point urban and tight-diamond interchanges," *ITE journal,* vol. 64, pp. 19-26, 1993.

[8] J. R. Pate and V. G. Stover, "Guidelines for the design of urban arterial interchanges in densely developed areas," 1992.

[9] Highway Capacity Manual, "HCM2010," *National Academy of Sciences. Yhdysvallat,* 2010.