Improving Level of Service on Urban Road Intersections: The Case of City of Larissa, Greece

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Abstract – *This paper examines the level of service (LOS) along a segment of road "Iroon Polytechniou" in the city of Larisa in Greece. "Iroon Polytechniou" is a heavily trafficked road of the city centre and former part of the national road network E65 and EO3. Level of service is calculated according to the methodology of highway capacity manual 2000 [1] through the average travel speed of vehicles on the trafficked surface. Given the fact that C or D LOS are set as target limits in this study, suggestions and recommendations are presented, where necessary, in order to improve calculated LOS up to the aforementioned limits. LOS is estimated on intersections of the road and all as a total. Intersection factors that lead to LOS values considered insufficient are highlighted respectively. Control delays of traffic lights turned out to be inadequate are pointed out and adequate improvement measures are proposed. Management of intersection deficiencies proves to radically increase provided LOS of examined segments.*

Keywords – *LOS management, urban road intersections, average travel speed, control delay, design management*

I. INTRODUCTION

Service quality audit requires quantitative measures to categorize operational conditions within a traffic flow. Level of service (LOS) is a qualitative indicator describing operational conditions within a traffic flow, namely speed and travel time, freedom to maneuver, traffic interruptions, ride comfort and travel convenience. Six LOS are defined for each type of facility that has analysis procedures available. Letters from A to F, designate each level, with LOS A representing the best operating conditions, meaning free flow and LOS F the worst, meaning traffic jam. Each level of service represents a range of operating conditions and the driver's perception of those conditions. It should be noted, that safety is not included in the factors that establish service levels [1, 2] (Table I).

TABLE I: LOS REPRESENTATION

LOS	Description
A	Highest driver comfort; free flowing
B	High degree of driver comfort; little delay
C	Acceptable level of driver comfort; some delay
D	Some driver frustration; moderate delay
E	High level of driver frustration; high levels of delay
F	Highest level of driver frustration; excessive delays

II. CALCULATION METHODOLOGY

The average travel speed of vehicles along an urban road stands for the determinant of the operating LOS. The methodology includes the under mentioned steps for determination of urban street LOS:

- Define segments and sections.
- Define length of segments.
- Define number of intersections.
- Determine urban street classification (Table II).

TABLE II: STREET CLASSIFICATION (SC)

FUNCTIONAL CATEGORY			
Principal arterial		Minor arterial	
DESIGN CATEGORY			
High-speed(I)	Suburban (II)	Intermediate (III)	Urban (IV)

- Determine free-flow-speed (Table III).

TABLE III: DEFAULT FFS VALUES

STREET CLASS			
I	II	III	IV
FREE FLOW SPEED, FFS (km/h)			
80	65	55	45

– Calculate running time, as follows:

$$T_{Ri} = T_R L_i ,$$

Where: T_{Ri}= running time, T_R= running time/km, L_i=length of segment.

– Calculate intersection control delay:

$$d = d_1(PF) + d_2 + d_3 ,$$

Where: d_1= Uniform delay(s/veh), PH= Progression adjustment factor, d_2= Incremental delay, (s/veh), d_3= Initial Queue delay (s/veh).

– Uniform delay (s/veh):

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]} ,$$

where, d_1= Uniform delay, X=degree of saturation, C= cycle length (s), and g= effective green time for lane group (s).

– Progression adjustment factor:

$$PF = \frac{(1-P)f_{PA}}{1-\frac{g}{C}} ,$$

$$P = R_P \frac{g}{C} ,$$

Where: PF= progression adjustment factor, P= proportion of all vehicles arriving during green, g/C= effective green time ratio and f_{PA}= supplemental adjustment factor for platoon arrival during the green.

– Capacity & saturation:

$$c = Ns\frac{g}{C},$$

Where: c= capacity of through lane at the intersection (veh/h), s= adjusted saturation flow per through lane (veh/h) and g/C= effective green time per cycle for the through movement at the intersection.

$$s = s_o N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} ,$$

Where: s= saturation flow rate for subject lane group (veh/h), s_o= base saturation flow rate per lane (pc/h/ln), N= number of lanes in lane group, few= adjustment factor for lane width, f_{HV}= adjustment factor for heavy vehicles in stream, f_g= adjustment factor for approach grade, f_p=adjustment factor for parking spaces and activity, f_{bb}= adjustment factor for blocking effect of local bus that stop within intersection area, f_a= adjustment factor for area type, f_{LU}= adjustment factor for lane utilization, f_{LT}= adjustment factor for left turns on lane group, f_{RT}= adjustment factor for right turns in lane group, f_{Lpb}= pedestrian adjusted factor for left turn movements and f_{Rpb}= pedestrian-bicycle adjustment factor for right turn movements.

– Incremental delay, (s/veh):

$$d_2 = 900T\left[(X-1)^2 + \frac{8kIX}{cT}\right],$$

Where: d_2= incremental delay (s/veh), T= duration of analysis period (h), k= incremental delay factor that is depended on controller settings, I= upstream metering adjustment factor, c= lane group capacity and X= degree of saturation.

– Initial Queue delay (s/veh):

$$d_3 = \frac{1800\, Q_{b\,(1+u)t}}{cT},$$

Where: Q_b= initial queue at the start of period T (veh), c= adjusted lane group capacity (veh/h), T= duration of analysis period (h), t= duration of unmet demand in T (h) and u= delay parameter.

– Compute average travel time by segment:

$$S_A = \frac{3600\, L_i}{T_{Ri} + d},$$

Where: T_{Ri}= running time/segment, d= control delay, L_i = length/segment.

– Calculate average travel time over entire facility:

$$\Sigma S_A = \frac{3600\, \Sigma L_i}{\Sigma T_{Ri} + \Sigma d},$$

Where: ΣT_{Ri}=total running time, Σd= total control delay, ΣL_i = total length of study section.

– Determine LOS: from the HCM 2000 Table IV, based on average travel speed and street class.

TABLE IV: URBAN STREET LOS BY CLASS & AVERAGE TRAVEL TIME

SC	**I**	**II**	**III**	**IV**
Range of FFS	90-70 (km/h)	70-56 (km/h)	56-50 (km/h)	55-40 (km/h)
Typical FFS	80 (km/h)	65 (km/h)	55 (km/h)	45 (km/h)
LOS	**Average travel time (km/h)**			
A	>72	>59	>50	>41
B	>56-72	>46-59	>39-50	>32-41
C	>40-56	>33-46	>28-39	>23-32
D	>32-40	>26-33	>22-28	>18-23
E	>26-32	>21-26	>17-22	>14-18
F	>26	>21	>17	>14

III. CASE STUDY

The study section of road "Iroon Polytechniou" begins from intersection "Iroon Polytechniou" / "23rd October" (I-23) to intersection "Iroon Polytechniou" / "Panagouli" (I-P). This road segment is a divided multilane arterial with important mobility and access function. It is a ring road of the city center, connected with principal arterials and provides usually exclusive left-turn lanes, has five control signals and some parking and pedestrian activity. By the functional and design characteristics the road section is an intermediate minor arterial. Street class by criterion illustrated at Table V.

TABLE V: STREET CLASS

Criterion	Street classification
Functional category	Minor arterial
Design category	Intermediate
Default FFS (km/h)	55

The under-study segment provides five control signals but the street classification forced the separation at sub-segments longer than 200 m. The segment separated at three basic sub-segments based on the significance of the controlled intersections. This segmentation is illustrated at Table VI and Fig.1.

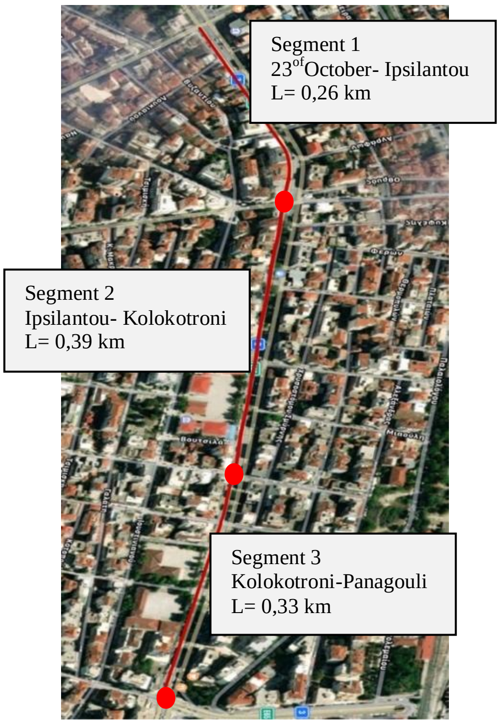

Fig. 1: Study Segments [3]

TABLE VI: INTERMEDIATE STREET SEPARATION

SEGMENT1	L: 0.26 km Control: pre-timed (70 s) g_{Lt} = 7 s g_{Th} = 37 s 637 veh/h 45 veh/h Movement: TH / LT Exclusive left turn
SEGMENT 2	L: 0.39 km Control: pre-timed (70 s) g_{Lt} = 11 s g_{Th} = 44 s 763 veh/h 51 veh/h 31 veh/h Movement: TH/LT/RT Exclusive left turn
SEGMENT 3	L: 0.33 km Control: pre-timed (70 s) g_{Lt} = 12 s g_{Th} = 18 s 1,730 veh/h 311 veh/h 311 veh/h 58 veh/h Movement: TH/LT/RT Exclusive left turn

The length of the study segment and sub-segments measured by Google earth application, as well the lane width. The segment is on a flat terrain so grade is set as zero. The adjustment factors are estimated respectively.

The control signals cycle (C) and effective green time (g) measured by timer. The intersections provide exclusive left-turn lane with separated left-turn signal. Total effective green time per segment (Σ g_i) depending on the proportion of traffic demand per permitted movement (Table VII). The signal cycle is pre-timed at 70 s all over the section.

TABLE VII: TOTAL EFFECTIVE GREENTIMEPER SEGMENT (Σ G_I) DEPENDINGON THE PROPORTIONOF TRAFFICDEMANDPER PERMITTEDMOVEMENT

S_i	% LT	g_{LT} (s)	%TH-RT	g_{TH-RT} (s)	Σ gi (s)
S_1	5	7	95	37	35.421
S_2	7	11	93	44	41.817
S_3	18	12	82	18	16.921

Traffic volume measured on the field by observation per segment, per permitted movement and per vehicle class for some days of September and October at peak hours for 1-hour analysis period. For the estimation of LOS were used maximum values of traffic volumes. All the vehicles were reduced to passenger cars by equivalent passenger cars units from Table VIII.

TABLE VIII: PASSENGER CARS EQUIVALENT [SOURCE: TRANSPORT AND COMMUNICATION MINISTRY]

Vehicle type	PCE
Motorcycles	0.5
Passenger cars, Small trucks	1.0
Buses, trucks, Car tractors	2.0
Dumped trucks, Articulated buses	3.0

The right site of intersection is full of parking spaces and every sub-segment has at least one bus station. The number of parking spaces and bus station measured on the field. The area is not a central business district (CBD) so the adjustment factor for area type set as unit (default value).

Base saturation flow, adjustment factor for lane utilization and adjustment factors of pedestrian's and bicycle's movements are set as default values from manual.

The arrival type selected by tables according to data from field measurements, to determine PF (progression adjustment factor) and P (proportion of all vehicles arriving during green). Factor k is set as default value (k=0.5), factor I estimated for degree of saturation <=1.0. R_p (arrival rate) and f_{PA} (supplemental adjustment factor for platoon arrival during the green) and Running time per km (TR) are set by default values by tables of HCM 2000 [1].

Initial queue observed in the field at the beginning of analysis periods and duration of unmet demand of analysis period (t) and delay parameter (u) set by manual's Table based on five cases.

IV. TABLE RESULT

Table Worksheet for Los Estimation			
Input data			
Parameters	S_1	S_2	S_3
C (s)	70.000	70.000	70.000
g (s)	35.421	41.817	16.921
g/C	0.506	0.598	0.248
X (v/c)	0.437	0.455	2.497
c (veh/h)	1,456	1,679	693
AT	5	5	1
L (km)	0.260	0.390	0.323
Qb (veh)	3	4	28
SC	III	III	III
FFS (km/h)	55	55	55
v	637	764	1,730
N	2	2	2
s	1,438	1,404	1,394
so	1,800	1,800	1,800
Fw	1	1	1
w	3,6	3.6	3.6
Fhv	0.991	0.994	0.985
HV%	0.04	0.03	0.03
Et	24	22	52
Fg	1	1	1
G%	0	0	0
Fp	0.850	0.833	0.835
Nm	40	47	46
Fbb	0.998	0.998	0.996
Nb	1	1	2
Fa	1	1	1
Flu	1	1	1
Flt	0.950	0.950	0.950
Plt	0.071	0.066	0.180
Frt	1	0.994	0.995
Prt	0	0.040	0.033
Flpb	1	1	1
Frpb	1	1	1
TR	88	75	75
TRi	22.9	29.3	24.2
Delay at intersections			
Parameters	S1	S2	S3
d1 (s)	11	8	27
k	0.5	0.5	0.5
I	0.90	0.89	0.90
d2 (s)	1	1	2,824
PF	0	0	1
P	0.844	0.997	0.083
Rp	1.667	1.667	0.333
Fpa	1	1	1
d3 (s)	7	9	146
T	1	1	1
u	1	1	1
t	1	1	1
Case d_3	IV	V	V
d (s)	12	9	3006
ST (s)	35	39	3030
SA (km/h)	27	36	0.4
LOSi	D	C	F
LOS estimation			
Σ ST	6131		
Σ L	0.97		
Σ SA (km/h)	0.6		
Σ LOS	F		

V. CONCLUSIONS

The level of service of segment 1 (D) with an average travel speed at 27 km/h presents a lower from the acceptable LOS, namely E. The control delay reaches 12 sec and the average travel time of the segment with length 260 m is 35 s.

The LOS of segment 2 is C, with average travel speed at 36 km/h and control delay for drivers at 9 s. The average travel time of the segment with length 390 m is 39 s.

The LOS of segment 3 is F. The average travel speed is less than 1 km/h with control delay at 50 min and average travel time at 51 min for a segment length 330 m.

The traffic volumes that used for the estimation related to peak hours, nonetheless segment 1 and 2 appears satisfying level of service with imperceptible traffic delay for drivers.

Segment 3 appears unacceptable LOS with very high traffic delay for drivers and long queuing. The segment includes other 2 control signals that measured in the field and do not particularly affect the traffic flow, so the biggest amount of delay appears at the last control signal of segment 3.

The total LOS is considered frustrating. The delay for drivers happens to be annoying and unacceptable. The significance of the section based on everyday traffic activity require at least E LOS for peak hours and C in general. The road section must be improved in terms of control, roadway and traffic conditions to improve the LOS for drivers.

Service of section is bad due to the weaknesses of segment 3. The conditions of segment 3 must be reviewed and optimized for a better LOS.

VI. RECOMMENDATIONS

The affecting factors of traffic capacity must be reviewed and optimized. The basic parameter that affects the LOS of segment 3 is the effective green time (g), which seems insufficient at 12 s and 18 s for traffic volumes over 1,500 veh/h. The queuing due to small green phases and the green time can increase the total LOS themselves. LOS can be E if effective green time reaches the 44 s and the average travel speed reaches over 14 km/h. This seems to be difficult without affecting the service of control signals in all directions of intersection.

The effective green time can be increased with multiple modifications at signalization conditions [4, 5, 6].

- Small increase of effective green up to the time that it does not affect traffic capacity at quadrilateral junction.
- Alternative effective green time based on traffic demand.
- Installation of pedestrian stop button to increase the green phase when pedestrian activity does not exist.

Excluding the above, traffic and roadway conditions at segment 3 could be modified [7]. The simulation resulted that if effective green time reaches 32 s and the segment provides three traffic lanes, the LOS will be E at peak hours. Some modifications on the roadway and traffic conditions are the following:

- If parking spaces from segment 3 are removed from the section, it will result in three traffic lanes with one common right-turn lane.
- Also, segment 3 could provide one exclusive left-turn lane and one common left-turn lane to serve the left-turn high traffic volume, with a modification at the entrance of "Panagouli" south intersection (Fig. 2).

Fig. 2: modification at intersection- providing 2 left-turns (one exclusive and one shared) to service the traffic demand at left-turns of segment 3

- As regards the geometric characteristics, one important modification is the length of exclusive left-turn lane (Fig. 3). The length is considered inadequate for the measured traffic volume and causes blocking of through lane stream.

Fig. 3: Increase the length of left-turn lane to avoid the through-lane blocking cause of left-turn traffic demand

The suggestions above form immediate and financial proposals to increase the LOS. In addition, large-scale constructions could be designed for this purpose, such as a new road infrastructure or widening of existing facility or a roundabout (Fig. 4).

Fig. 4: Tail of study section (segment 3) on intersection with "Panagouli" street (continuation of street "Farsalon"). Recommendation for construction of roundabout on site

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