PDHonline Course C783 (2 PDH)

Identifying Optimum Lane Configuration Using CMA

Instructor: Jeffrey W. Buckholz, PhD, P.E., PTOE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

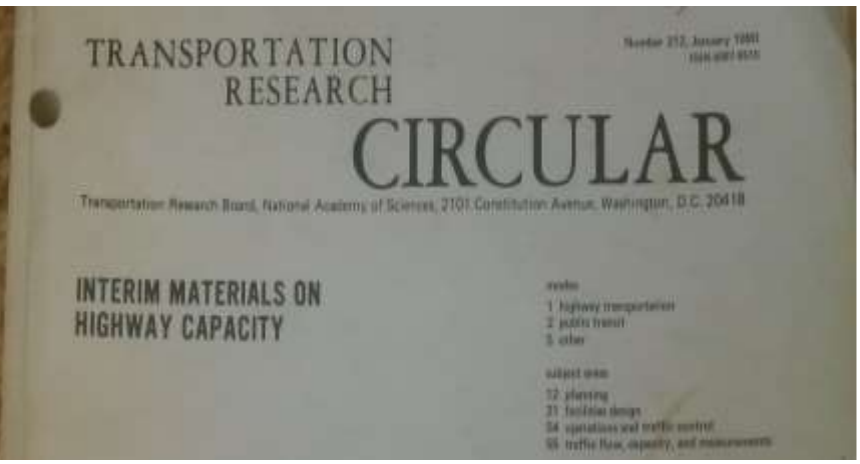
An Approved Continuing Education Provider

Identifying Optimum Lane Configuration Using CMA

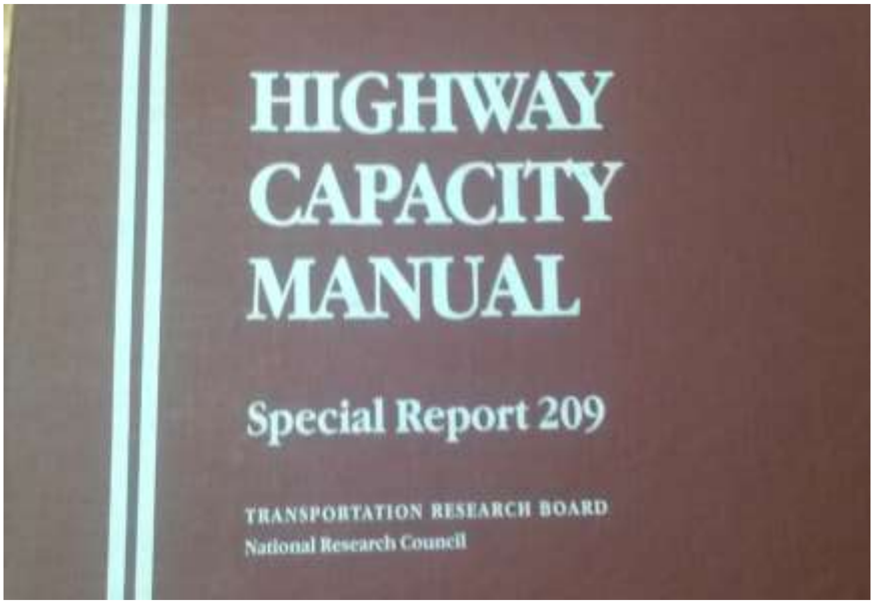
Jeffrey W. Buckholz, PhD, P.E., PTOE

COURSE CONTENT

An excellent way to identify the optimum lane configuration and associated signal phasing at a signalized intersection is through the use of simplified Critical Movement Analysis (CMA). CMA is a planning-level analysis methodology that first appeared in the Transportation Research Board's Circular 212 back in 1980.

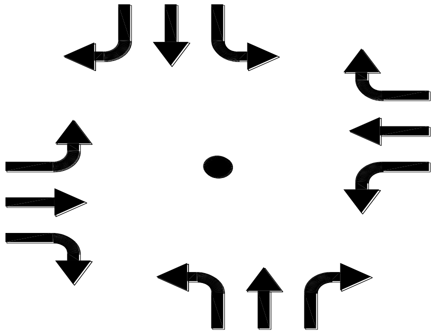


The technique was brought into the transportation engineering mainstream with publication of the 1985 Highway Capacity Manual.

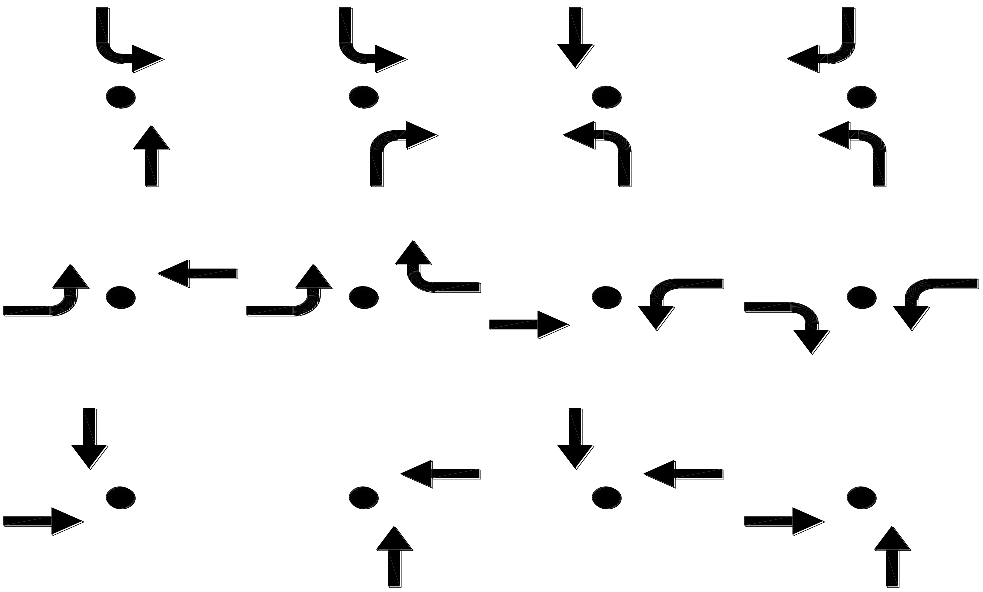


The methodology is simple enough to be performed by hand yet provides the analyst with an excellent feel for how a signalized intersection can be expected to perform under a given set of hourly traffic volumes. It is a great tool for analyzing intersections under future conditions where traffic volumes may be approximate and where detailed signal timing information and traffic stream characteristics (such as percent trucks or the peak hour factor) may be unknown or known with little certainty. While going through the CMA procedure the traffic analyst develops an excellent feel for which lane additions will improve traffic operations and which will not. The procedure is also useful in determining which signal phasing pattern will produce optimum capacity results.

Over the last 30 years Critical Movement Analysis has given way to highly computerized procedures that are much more accurate, but which have a much higher data input need. The use of such automated procedures can result in the analyst getting bogged down in detail and "losing touch" with the operational needs of the intersection. Consequently, when designing intersections, CMA is a great first step in the analysis process that allows one to quickly determine the optimum lane configuration and associated signal phasing. CMA is based on the simple principal that no two streams of conflicting traffic can cross through the intersection at the same time (or we would have the obvious accident). For example, northbound left turns and southbound thru movements cannot proceed at the same time and neither can westbound left turns and northbound thru movements. The complete set of conflicting and non-conflicting volumes at a typical 4-leg intersection can be depicted as follows.

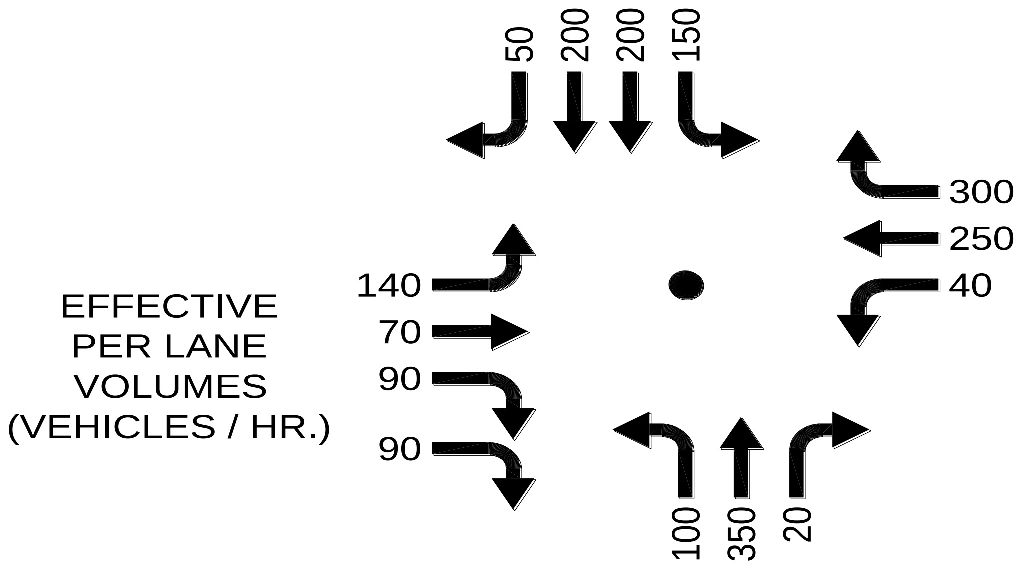


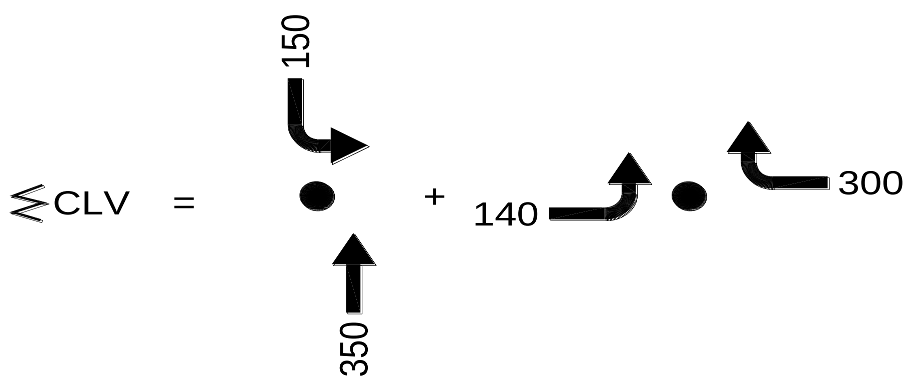
ALL MOVEMENTS



CONFLICTING MOVEMENTS

CMA identifies the set of conflicting movements that require the most time to serve (assuming the intersection were signalized) and then sums up the hourly per-lane volumes associated with this "critical" set of movements. This sum, known as the Sum of the Critical Lane Volumes (SCLV), is then compared to a simple table to determine whether the intersection as designed will operate BELOW capacity, NEAR capacity, AT capacity, or ABOVE capacity.

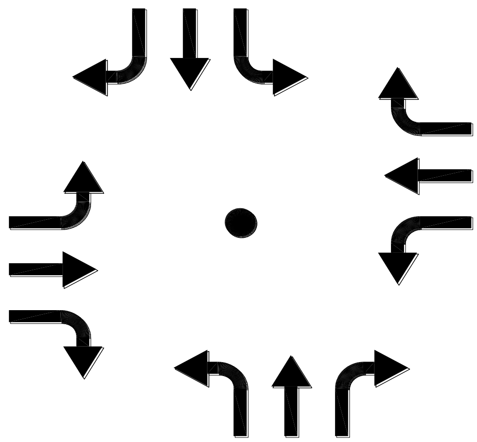




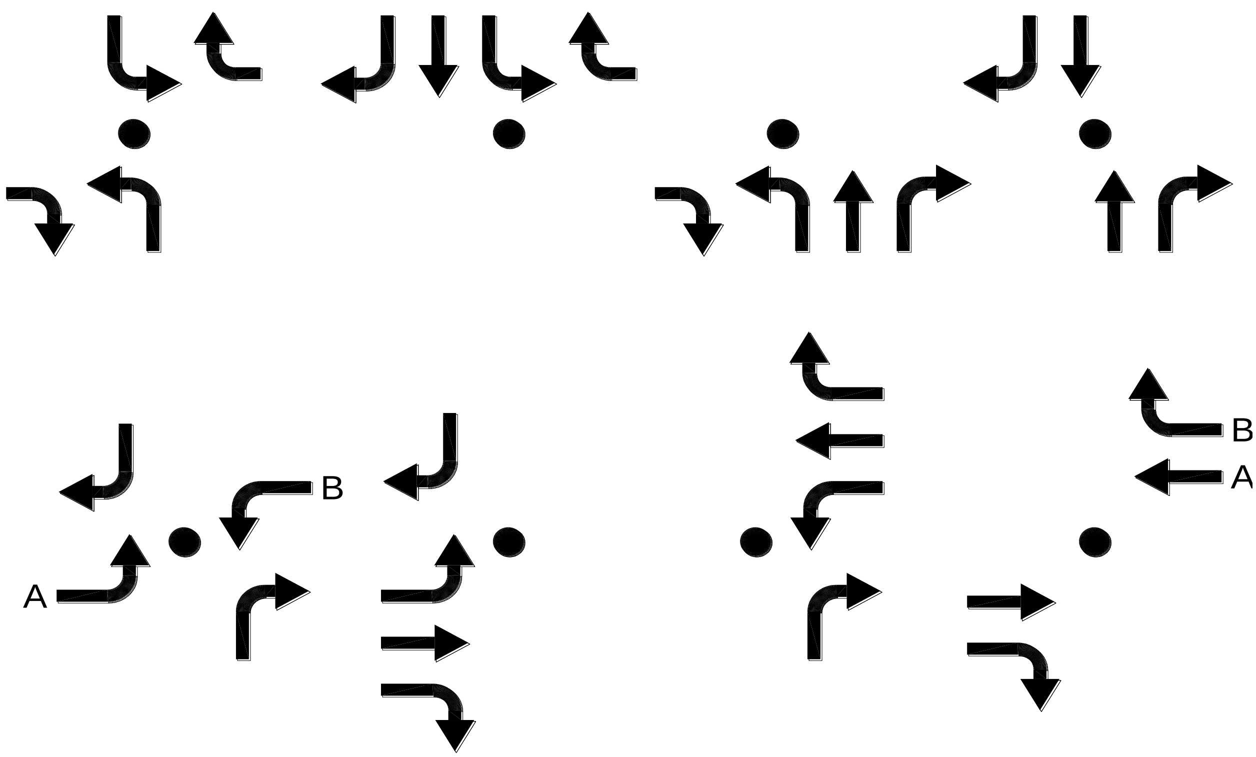
$$\sum CLV = 500 + 440$$

$$\sum CLV = \underline{\underline{940}}$$

Certain movements can proceed at the same time and are, therefore, non-conflicting.



ALL MOVEMENTS



NON-CONFLICTING MOVEMENTS

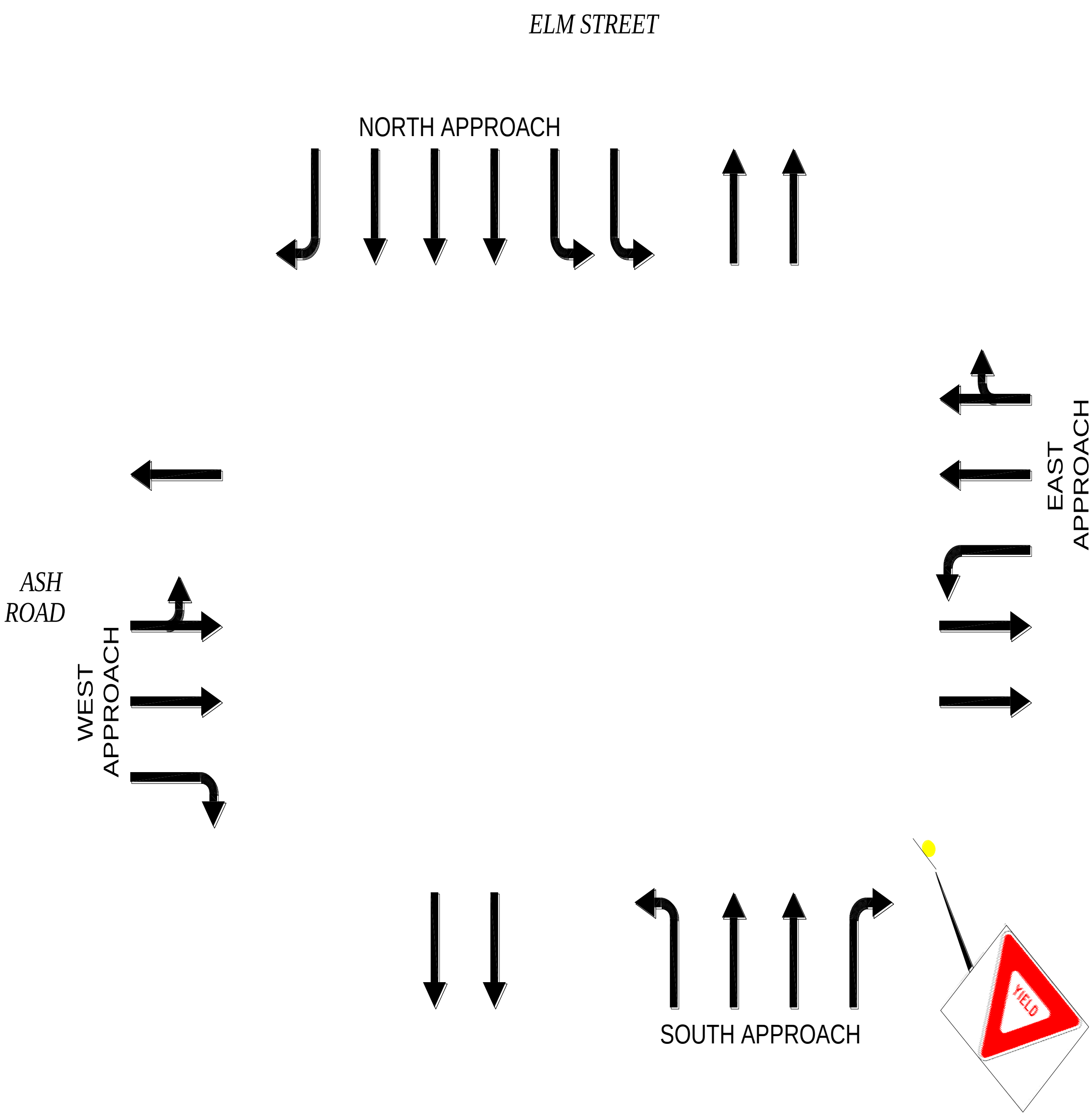
Whenever there are such simultaneous movements, only one of the two movements will contribute to the SCLV. For example, in the above figure either movement A or movement B will contribute to the SCLV, but not both.

In this course we present my version of Critical Movement Analysis, which I call "Simplified Critical

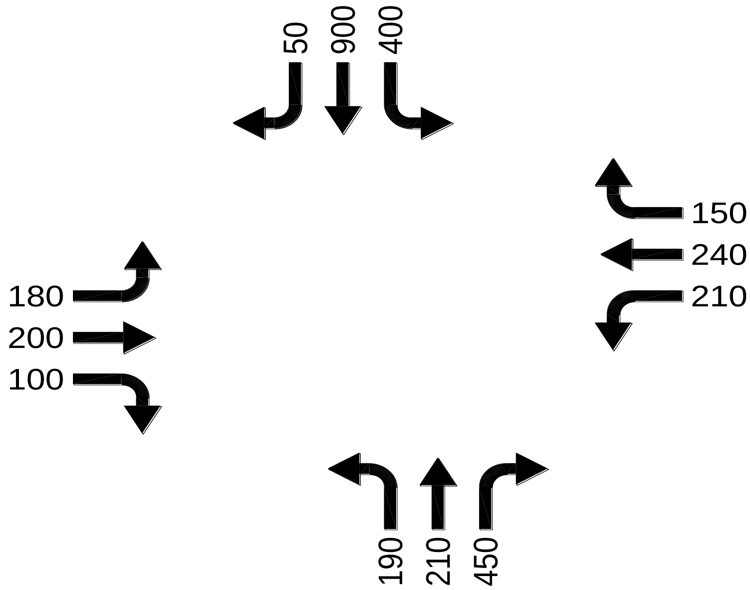
Movement Analysis". Others have developed more detailed techniques based on the CMA paradigm, techniques that may provide slightly better results but which require much more input information and which involve more complex calculations. In my experience, this simplified procedure answers the really important questions without getting bogged down in details that might not even be available for a design horizon that is 10 or 20 years in the future.

Only three inputs are needed to perform Simplified Critical Movement Analysis:

1.) The proposed intersection lane configuration,

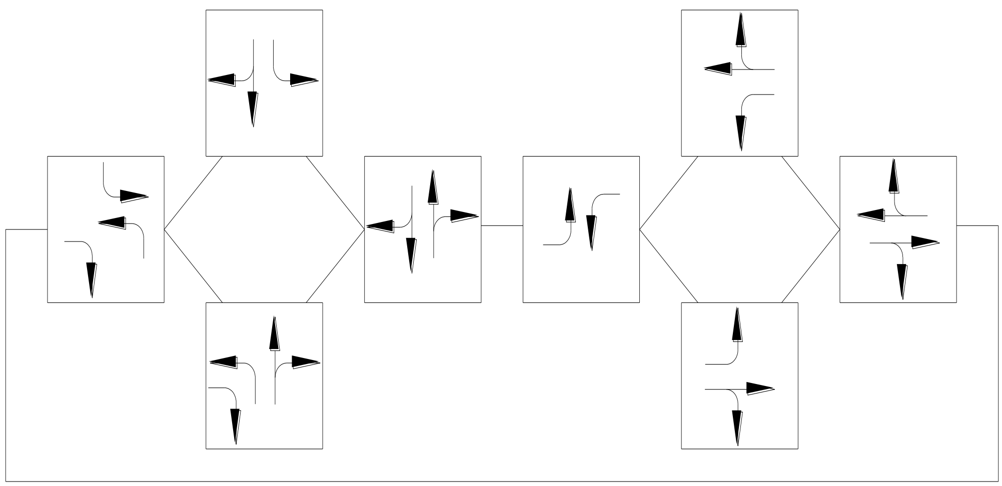


2.) The hourly turning movement volumes for the design year under study, and



PROJECTED 2025 AM PEAK HOUR VOLUMES

3.) The proposed traffic signal phasing.



The output obtained from the procedure is the Sum of the Critical Lane Volumes (SCLV). This output is compared to the values in the following table to determine how well we expect the intersection to operate:

SCLV <= 800	WAY UNDER capacity
800 < SCLV <= 1200	UNDER capacity
1200 < SCLV <= 1400	NEAR capacity
1400 < SCLV < =1800	OVER capacity
1800 < SCLV	WAY OVER capacity

The terms in the table can be roughly interpreted as follows:

WAY UNDER capacity – intersection may not warrant signalization
UNDER capacity – no cycle failures
NEAR capacity – possible cycle failures
OVER capacity – frequent cycle failures
WAY ABOVE capacity – multiple cycle failures with recurring queues

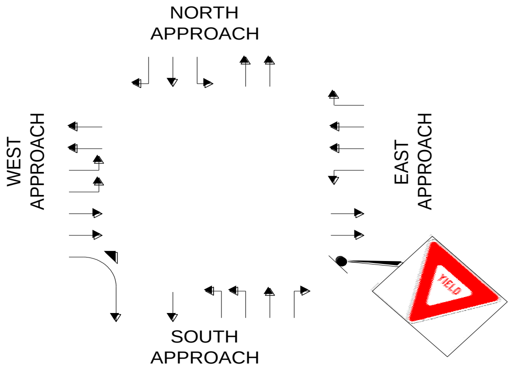
A cycle failure occurs when the traffic waiting on one or more approaches to the intersection does not clear the intersection on the first green indication it receives and must wait through an entire cycle. Motorists hate this and traffic engineers try to avoid intersection designs that create this situation whenever possible.

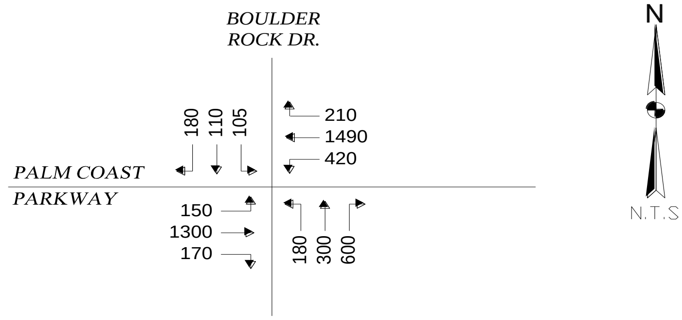
The first and last terms (WAY UNDER and WAY OVER) are terms that I have added to the procedure based on experience. When the SCLV is greater than 1800 the intersection totally breaks down and there is nothing you can do from a signal timing standpoint that will make the situation work – you need either less traffic or more lanes. When the SCLV is greater than 1800 you can expect to have a lot of unhappy motorists on your hands and considerable political pressure to "do something". The situation is also not very attractive when you SCLV is over 1400 but the motorists outcry is much less; there are a lot of intersections that experience this level of operation during peak hours and motorists seem to be able to deal with it.

The simplified CMA technique is best understood by reviewing a series of examples.

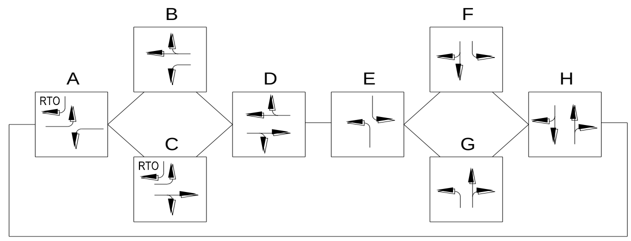
EXAMPLE 1: HIGH CAPACITY INTERSECTION WITH QUAD LEFT TURN PHASING

The upper panel of Figure 1 provides the year 2020 PM peak hour turning movement volumes, the proposed future lane configuration, and the proposed traffic signal phasing for the intersection of Palm Coast Parkway and Bolder Rock Drive.

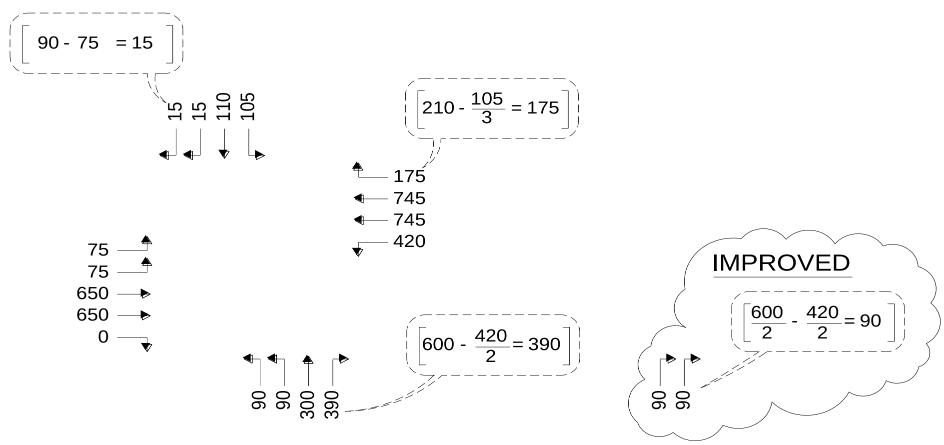




2020 PM PEAK HOUR
PEAK SEASON TURNING MOVEMENTS



FULL QUAD LEFT TURN



$$SCLV = MAX\begin{bmatrix} 75+745 \\ 420+650 \end{bmatrix} + MAX\begin{bmatrix} 90+110 \\ 105+390 \end{bmatrix} = 1565 \text{ (OVER)}$$

FIGURE 1

Will the proposed lane configuration and signal phasing adequately handle the future volumes? Let's use CMA to find out.

The first step is to apportion the volumes by lane for each movement to obtain the effective lane volumes. There are 2 lanes for the west approach left turn movement so the 150 left turns are apportioned as 75 vehicles per lane. There is only 1 lane for the north approach thru movement so all of the 110 southbound thru vehicles must use this lane.

The results of the apportioning are shown in the middle panel of Figure 1. Also shown in this panel are reductions in the lane volumes for all exclusive right turn lanes. Exclusive right turn lanes fall into one of four categories:

Category 1: A right turn lane that has its own receiving lane on the intersection street. This is the case for the west approach right turn movement at the Palm Coast Parkway/Boulder Rock Drive intersection. As long as this hourly right turn volume is less than 1200 vehicles (which is almost always the case) it can be removed from the analysis with its effective per lane volume set to zero for the purpose of critical movement analysis.

Category 2: A right turn lane controlled by a right turn overlap (RTO) arrow. This is the case for the north approach right turn movement at the Palm Coast Parkway/Boulder Rock Drive intersection. A 1-for-1 reduction in right turn volumes, up to the amount of the corresponding per-lane overlapping left turn volume, is made whenever a RTO is present. In this example, there are 75 vehicles per lane in the west approach left turn movement that overlaps with this north approach right turn movement so 75 is deducted from the per lane right turn volume of 90 producing 15 effective right turns per lane.

Category 3: A right turn lane controlled by a YIELD sign. This is the case for the south approach right turn movement at the Palm Coast Parkway/Boulder Rock Drive intersection. A 1-for-2 reduction in right turn volumes, up to the amount of the corresponding per-lane overlapping left turn volume, is made for yield control. In this example, there are 420 vehicles per lane in the east approach left turn movement so 420/2 or 210 is deducted from the right turn volume of 600 producing 390 effective right turns.

Category 4: All other exclusive right turn lanes (such as the east approach right turn in this example) receive a 1-for-3 reduction in right turn volumes, up to the amount of the corresponding per-lane overlapping left turn volume. There are 105 vehicles per lane for the north approach left turn movement so 105/3 or 35 is deducted from the right turn volume of 210 producing 175 effective right turns for the east approach.

No reduction in volume is given for right turns made from shared lanes, only those made from exclusive lanes since only right turns from exclusive lanes can proceed at the same time as the corresponding left turn without being blocked by a thru vehicle.

The sum of the critical lane volume (SCLV) calculations are shown in the lower panel of Figure 1. The first step in making these calculations to add up the two sets of effective per lane conflicting volumes in the main street (east-west) direction and then take the maximum of the two values. In this example, 75 west approach lefts conflict with 745 east approach thru's and 420 east approach lefts conflict with 650 west approach thru's. The larger conflicting sum is **1070** with the east approach left/west approach thru being the critical combination of conflicting movements in the east-west direction.

The next step is to add up the conflicting per lane volumes in the north-south direction. In this example, 90 south approach lefts conflict with 110 north approach thru's and 105 north approach lefts conflict with 390 south approach rights. The larger conflicting sum is **495** with the notth approach left/south approach right being the critical combination of conflicting movements in the north-south direction.

Summing the critical effective lane volumes in both directions produces a total of **1565** which represents an OVER capacity condition.

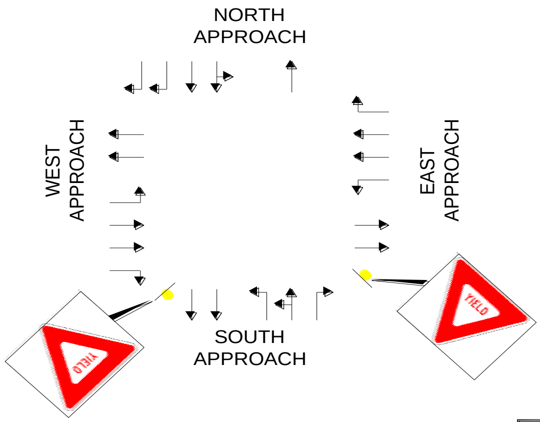
So we see that the proposed lane configuration is not that great. How can we make things better? We make things better by reducing the critical movement volumes. In this example, adding a second right turn lane to the south approach as shown within the "cloud" in the middle panel of Figure 1 produces a SCLV of 1270 which is NEAR capacity – a preferred result. Notice that, with the addition of this turn lane, the critical volume pair in the north-south direction switched.

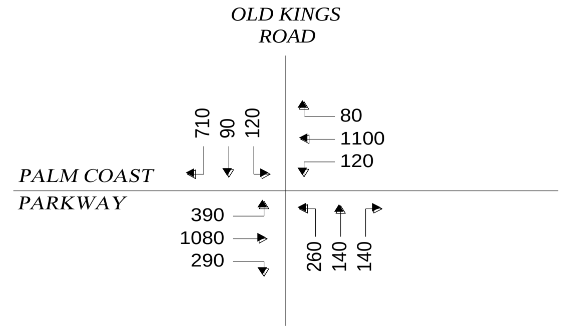
When adding this second south approach right turn lane we need to make sure there are a sufficient number of receiving lanes in the eastbound direction to accommodate it, which there are in this case. All approach lanes must have the appropriate number of receiving lanes, lanes cannot simply vanish or magically merge together in the middle of an intersection.

There is one more complicating factor. We just completed the analysis for the weekday PM peak hour, but what about the weekday AM peak hour? In a real life situation we would need to check the AM peak hour too using the AM traffic volumes since traffic volumes and patterns in the morning are usually quite different than in the afternoon, especially along a commuter route. The intersection configuration may need to be modified further to make the intersection operate properly during the morning rush hour. And, if the intersection is in a shopping or recreational area, we may need to check the weekend peak hour as well.

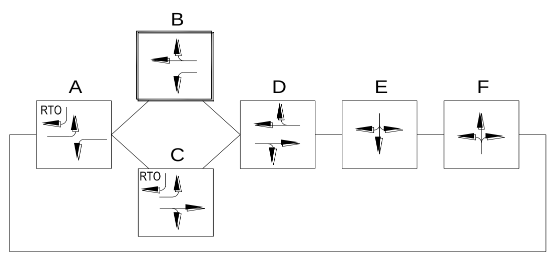
EXAMPLE 2: MEDIUM CAPACITY INTERSECTION WITH SIDE STREET SPLIT PHASING

The upper panel of Figure 2 provides the year 2020 PM peak hour turning movement volumes, the proposed future lane configuration, and the proposed traffic signal phasing for the intersection of Palm Coast Parkway and Old Kings Road.

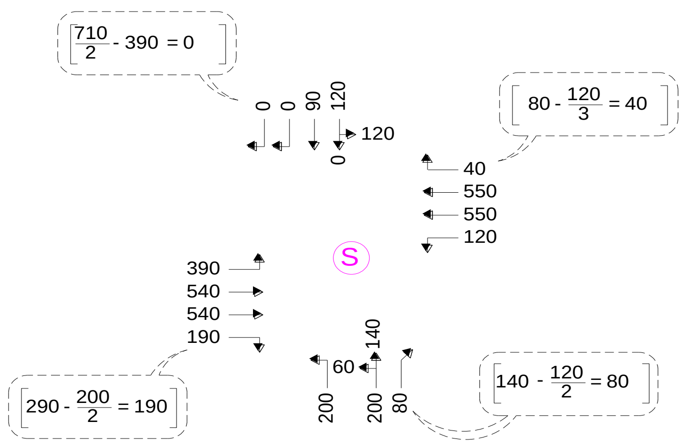




2020 PM PEAK HOUR
PEAK SEASON TURNING MOVEMENTS



SIDE STREET SPLIT PHASE



$$SCLV = MAX\left[\begin{matrix}\underline{120}+540\\ 390+\underline{550}\end{matrix}\right] + \underline{120} + \underline{200} = \underline{1260}\ (NEAR)$$

FIGURE 2

Notice that both the north and south approach have one shared thru/left turn lane and that both approaches operate during a separate phase (phase combination E for the north approach and phase combination F for the south approach). Also notice that there were no shared lanes in the previous example. Will the proposed lane configuration and signal phasing adequately handle the future volumes? How do we apportion volumes in these shared lanes? Again, let's use CMA to find out.

The first step is to apportion the volumes by lane for each movement to obtain the effective lane volumes. The Palm Coast Parkway volumes are apportioned just like we apportioned volumes in the previous example, as are the volumes for the exclusive right turn lanes on Old Kings Road. However, the left and thru movements on Old Kings Road use shared lanes and the logic for shared lanes is a bit different.

We want to minimize lane volumes wherever possible so, on the south approach where there is a total of 400 vehicles going left and thru, we balance the lane volumes for the exclusive left turn lane and the shared left/thru lane be assigning 200 vehicles to each lane. All 140 thru vehicles must use the shared thru/left lane so 60 of the 260 left turn vehicles (200-140) can use this lane as well. The remaining 200 left turn vehicles are assigned to the exclusive left turn lane.

When we try this procedure on the north approach, we run into a problem. Balancing the volumes for the thru only lane and the shared left/thru lane would result in 105 vehicles in each lane - but this cannot be since 120 vehicles desire to turn left and they must do so from the shared thru/left lane. The only workable solution is to assign all 120 left turn vehicles to the shared thru/left lane (making it a "de facto" exclusive left turn lane during this peak hour) and all of the 90 thru vehicles to the thru only lane. In this case, the lane volumes do not balance as desired.

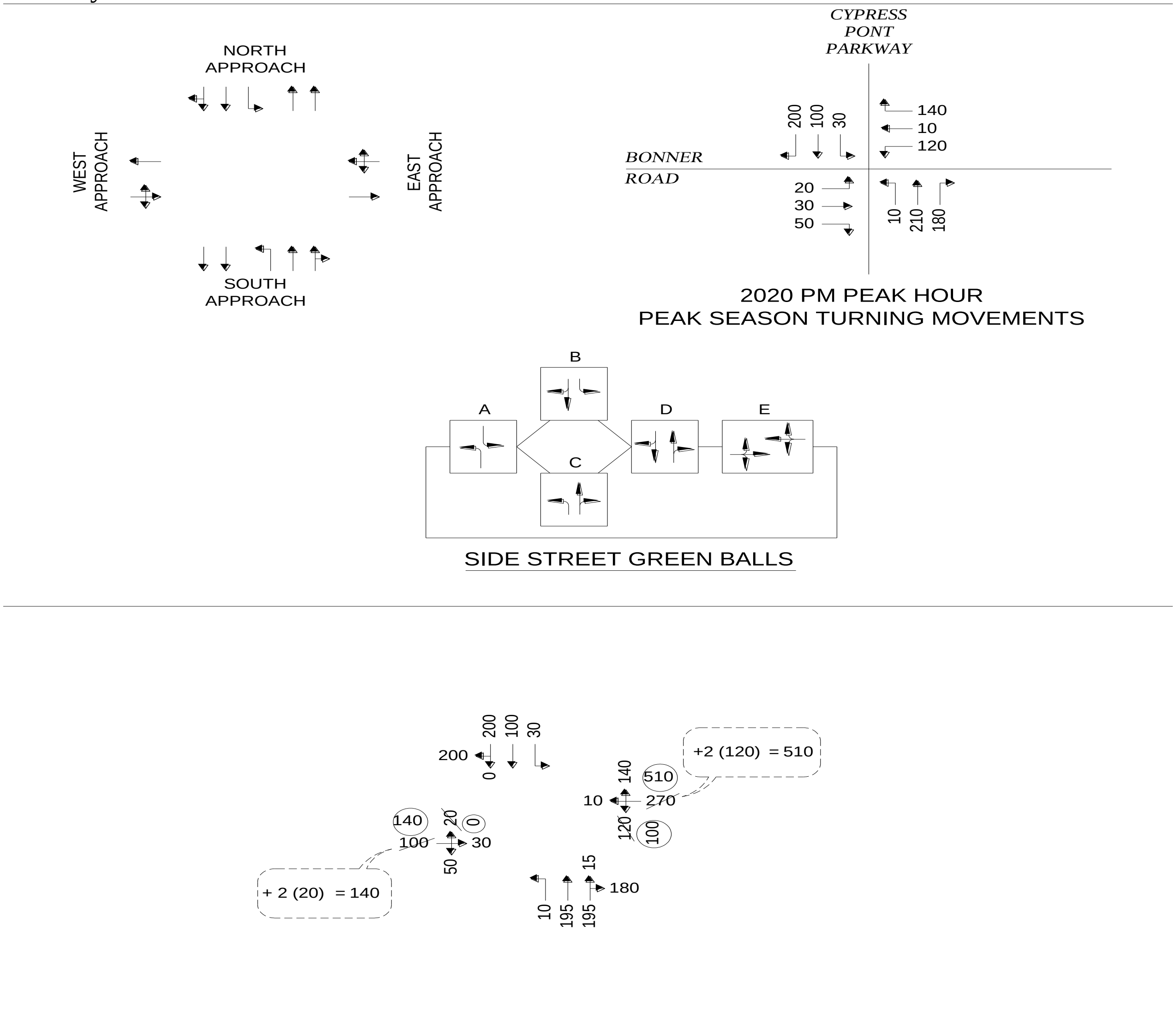
The results of the apportioning are shown in the middle panel of Figure 2. Also shown in this panel are reductions in the lane volumes for all exclusive right turn lanes using the same logic as was used in the previous example.

The sum of the critical lane volume (SCLV) calculations are shown in the lower panel of Figure 2 and they are similar to those of Example 1. The first step in making these calculations is to add up the two sets of effective per lane conflicting volumes in the east-west direction and then take the maximum of the two values. In this example, 120 east approach lefts conflict with 540 west approach thru's and 390 west approach lefts conflict with 550 east approach thru's. The larger conflicting sum is **940** with the west approach left/east approach thru being the critical pair of conflicting movements in the east-west direction.

Since we have a side street split phase with the north approach proceeding first and then the south approach, the conflicting per lane volumes in the north-south direction are handled differently than in Example 1. We simply take the largest per lane volume from each approach and add them together; **120** for the north approach thru/left lane and **200** for the south approach exclusive left turn lane (or for the shared thru/left lane, it doesn't matter since they are equal). Summing the critical effective lane volumes in both directions produces a total of **1260** which represents a NEAR capacity condition. If things also check out fine during the AM peak hour this intersection configuration and signal phasing should work well.

EXAMPLE 3: LOW CAPACITY INTERSECTION WITH SINGLE LANE APPROACHES

The upper panel of Figure 3 provides the year 2020 PM peak hour turning movement volumes, the proposed future lane configuration, and the proposed traffic signal phasing for the intersection of Cypress Point Parkway and Bonner Road.



$$SCLV = MAX\begin{bmatrix}10+200\\30+195\end{bmatrix} + MAX\begin{bmatrix}100+140\\0+510\end{bmatrix} = \underline{735}\ (\text{WAY UNDER})$$

FIGURE 3

Notice that both the east and west legs of the intersection have only one approach lane and these two shared lanes both receive the green indication at the same time (during phase combination E). Will the proposed lane configuration and signal phasing adequately handle the future volumes? How do we apportion volumes in these shared lanes, lanes which operate under the same phase combination? Once again it's CMA to the rescue.

As before, the first step is to apportion the volumes by lane for each movement to obtain the effective lane volumes. The main street Cypress Point Parkway volumes are apportioned as shown in the middle panel of Figure 3. The north-south approach left turn volumes are simply placed in their respective left turn lanes while the thru and right turn volumes are balanced out. It's not possible to balance the north approach thru and right volumes since all 200 right turns must be assigned to the shared thru/right lane (making it a "de facto" exclusive right turn lane during this peak hour).

Identifying the side street Bonner Road effective lane volumes starts with the realization that, in a shared lane environment, opposing left turns operating under simultaneous green indications cancel each other out (i.e. vehicles turn left at the same time). This is why the left turn volumes are struck through and replaced by their effective volumes - with the 20 west approach left turns becoming zero and, in the process, reducing the 120 east approach left turns to 100.

Since left turns block thru and right turn vehicles behind them, we also have to adjust the total side street approach volumes for single lane approaches to reflect this lane "impedance" produced by the left turn obstruction. This impedance is estimated in simplified Critical Movement Analysis by multiplying the left turns by a factor of 3 and adding it to the thru and right turn approach volume for the single lane. Alternatively, as is shown in Figure 3, the left turn volume is multiplied by a factor of 2 and added to the total volume for the approach; producing an equivalent result. This produces a total of 510 effective vehicles for the east approach and 140 effective vehicles for the west approach. In actuality, the factor by which the left turns are multiplied varies from 1.1 to 5 depending on the level of opposing traffic. However, to keep things simple in this simplified CMA, we always use a median value of 3.

The sum of the critical lane volume (SCLV) calculations are shown in the lower panel of Figure 3. The first step in making these calculations to add up the two sets of effective per lane conflicting volumes in the main street (north-south) direction, taking the maximum of the two values. In this example, 30 north approach lefts conflict with 195 south approach balanced thru's and right turns and 10 south approach lefts conflict with 200 north approach right turns. The larger conflicting sum is **225** with the north approach left/south approach thru-right being the critical combination of conflicting movements in the north-south direction.

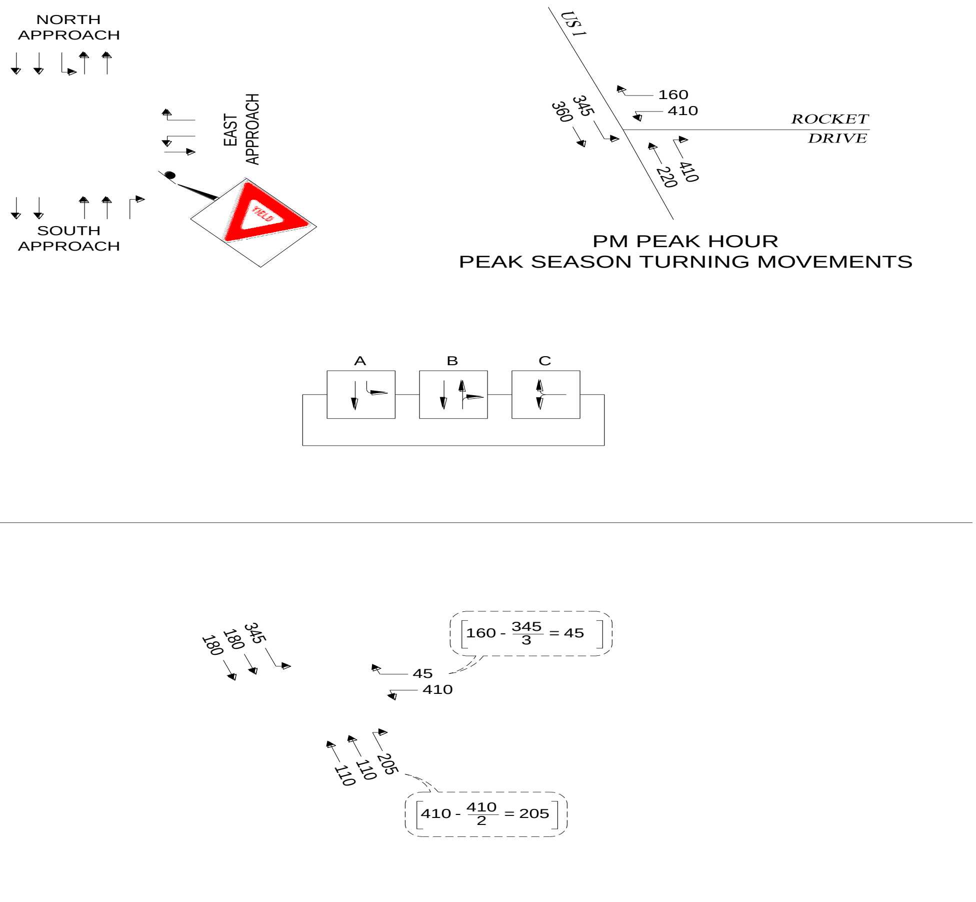
Then we sum the effective left turns and the effective total approach volumes in the east-west direction. In this example, 0 + 510 = 510 and 100 + 140 = 240 with the larger **510** being the critical volume.

Summing the critical effective lane volumes in both directions produces a total of **735** which represents a WAY UNDER capacity condition. If we also get WAY UNDER during the AM peak hour we may suspect that this intersection does not require signalized control.

It should be noted that, although you often find single lane approaches on the side streets of signalized intersections, this is not a good design. If an intersection is important enough to warrant signalization then it is also important enough to be provided with a full complement of side street approach lanes (at least 2 and preferably more). Side street capacity is severely reduced with only one approach lane, requiring valuable green time to be taken from the major street and given to the minor street.

EXAMPLE 4: T-INTERSECTION

The upper panel of Figure 4 provides the year 2020 PM peak hour turning movement volumes, the proposed future lane configuration, and the proposed traffic signal phasing for the intersection of US 1 and Rocket Drive – which is a "T" intersection.



$$\text{SCLV} = \text{MAX}\begin{bmatrix} 180 \\ 345+205 \end{bmatrix} + 410 = 960 \text{ (UNDER)}$$

FIGURE 4

Critical Movement Analysis can handle a wide variety of intersection types, including “T” intersections, 5-leg intersections, Single Point Urban Interchanges (SPUI), etc. The procedure is always the same, add up all of the critical conflicting lane volumes crossing through the middle of the intersection and compare it to the table values.

Will the proposed lane configuration and signal phasing adequately handle the future volumes for this “T” intersection? Let’s find out.

The main street US 1 volumes are apportioned as shown in the middle panel of Figure 4. The north approach left turn volume is simply placed in its left turn lane while the north and south approach thru volumes are balanced out. The south approach right turn has an exclusive lane that is YIELD controlled so the effective south approach right turn volume is calculated by subtracting out the corresponding side street left turn volume (divided by 2 for yield control).

The side street left turn volume is simply placed in its corresponding left turn lane while the side street right turn volume is reduced by 1/3 because it uses an exclusive lane with no special control.

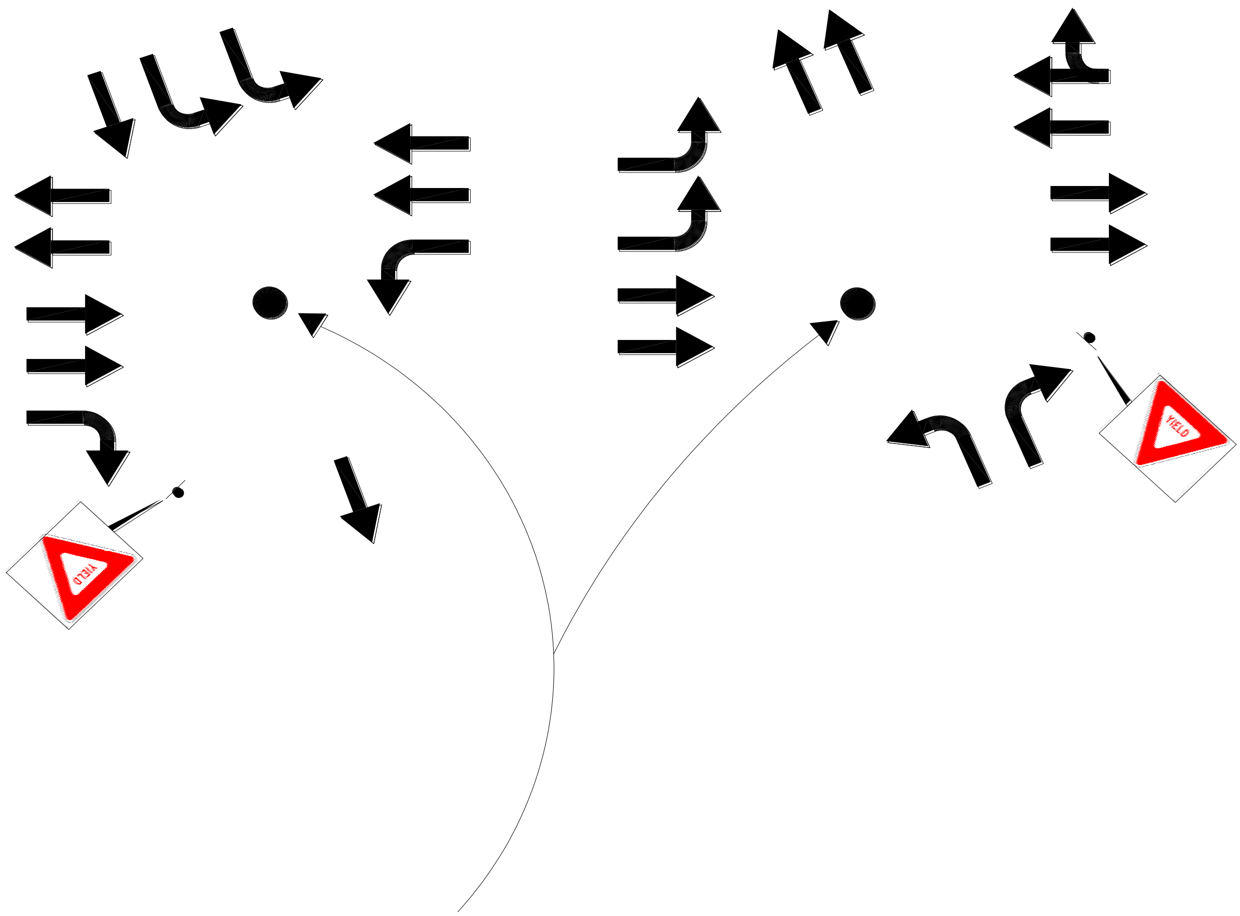
The sum of the critical lane volume (SCLV) calculations are shown in the lower panel of Figure 4. The first step in making these calculations is to add up the two sets of effective per lane conflicting volumes in the main street (north-south) direction and then take the maximum of the two values. In this example, 345 north approach lefts conflict with 205 effective south approach right turns and 0 south approach left turns conflict with 180 north approach thru’s. The larger conflicting sum is **550**.

The largest conflicting volume on the side street can be determined by simple inspection, it is **410** for the left turn lane.

Summing the critical effective lane volumes in both directions produces a total of **960** which represents UNDER capacity condition. If we also get acceptable operation during the AM peak hour then we have a workable intersection layout.

IN SUMMARY

Critical Movement Analysis (CMA) is a great planning tool to quickly evaluate future intersections with a minimum of inputs. The procedures simplicity is its primary strength - but also its major weakness. CMA procedure starts to break-down when you don’t have a single point of conflict for the conflicting movements (as with a compressed diamond interchange, see Figure 5) or when the intersection characteristics, traffic stream characteristics or signal phasing are not typical (narrow lanes, high percentage of large trucks, significant interference from transit buses or on-street parking, exclusive pedestrian phase, etc.). When we know that these complications will exist in the future, one needs to utilize the more complex computerized operational procedures found in the Highway Capacity Software and in proprietary intersection analysis software such as Synchro and VISSUM.



2 POINTS OF CONFLICT FOR A
COMPRESSED DIAMOND INTERCHANGE

FIGURE 5

