FULLY ACTUATED VS. SEMI- ACTUATED TRAFFIC SIGNAL SYSTEMS

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Introduction

ISTEA puts an emphasis on management systems. Traffic signals are a good example of a congestion management tool. The question arises of how to get the most for the highway dollar. This paper discusses the benefits and drawbacks of fully actuated versus semi - actuated signals. For comparison, pretimed signals with and without pedestrian times are included.

Qualitative Comparison

To discuss fully actuated versus semi-actuated signals in a system; it is first necessary to discuss them as isolated signals.

Semi-actuated isolated signals have detection on some or all movements except the mainline. Non-detected phases are controlled on a pretimed basis. Cycle length is allowed to change by varying the detected phase lengths. Split percentages for the mainline are then arrived at by dividing the fixed mainline phase into the variable cycle length. Sufficient green time (and therefore capacity) for the mainline is not guaranteed without additional delay to the other movements. Once the mainline's minimum green has been served, the non-coordinated phases can be served when a call arrives (with clearance times). Without the presence of a conflicting call, the signal normally will rest in the mainline phase.

Fully actuated isolated signals provide mainline detection at approximately five seconds before the stopline for dilemma zone protection. This detection is used for intersections with moderate to high speeds where dilemma zone protection is appropriate. Mainline detection allows for a variable mainline phase length to correspond with traffic flows on a moment by moment basis. Cycle and all phase lengths (and therefore splits) are allowed to correspond to traffic flows.

In a system, semi-actuated signals have an imposed cycle length. Non-coordinated phases vary their phase lengths in response to traffic flows and have imposed maximums for coordination (force-offs). The mainline phase receives the remainder of the cycle length after the non-coordinated phases have been served. Through coordination inputs, the mainline has a variable minimum phase length and a specific point (or period) in the cycle for yielding to the non-coordinated phases (called the yield point, usually one second). If there are no calls present at the point in the cycle where the coordination is ready to yield from the mainline to the non-coordinated phases, the non-coordinated phases will be skipped for an entire cycle length. If there is a call, the mainline phase will yield to the non-coordinated phases regardless of mainline vehicles in the dilemma zone. Mainline progression benefits by having the leading edge of the platoon start early as well as having a guaranteed latest start time. To offset this benefit, the non-coordinated phases must wait for the yield point regardless of the mainline traffic flows.

In a coordinated fully actuated signal system, both ends of the mainline bandwidth are allowed to vary within the coordination parameters. If the non-coordinated phases can be served in less time than the coordination constraints impose, additional time is provided to the mainline in the same way as a semi-actuated signal. If the non-coordinated phase's vehicle arrives late (after the semi-actuated signal's yield point), it can still be served during the permissive period instead of a single point in time without compromising the dilemma zone protection. (The semi-actuated

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system can be set up with a permissive period. without mainline detection; however, the signal usually will yield at the beginning of the permissive period.) Vehicles arriving early on the non-coordinated phases also can be served early if the mainline traffic will not be impeded.

Examples

Using a sixty second background cycle at a two phase semi-actuated intersection, a side street (non-coordinated phase) vehicle arriving one second after the yield point will be delayed 59 additional seconds for missing the yield point. If progression is good on the mainline, immediately following the yield point there should be very little traffic to delay the side street traffic. Yet, the side street vehicle is delayed for what is ordinarily considered an unacceptable amount of time.

In this situation, where the side street vehicle arrives late, a fully actuated signal would reduce the side street vehicle's delay by yielding after the platoon had passed out of the dilemma zone instead of waiting almost an entire cycle length.

If two or more mainline vehicles are running a little behind the end of the bandwidth, they can be caught in the dilemma zone when a semi-actuated system yields. This may cause a rear-end accident, just because the side street vehicle could not be delayed another two to four seconds.

In the second situation, where there is a side street call and mainline vehicles are running behind the end of the normal bandwidth, the full actuated system's bandwidth is increased and dilemma zone protection is provided for the mainline vehicles with little additional side street delay.

In a third example, a side street vehicle arrives prior to the end of the normal end of the bandwidth. Mainline traffic is light and the platoon passes through the intersection earlier than expected. The fully actuated system serves the side street vehicle after the end of the platoon passes by instead of waiting for a semi-actuated yield point.

Options

Free-run operation may be desirable on occasions at intersections that otherwise would be part of a coordinated system. Mainline detection provides the ability to go to isolated fully actuated control. This function can be called by a time clock, allowing coordination for part of a day and free run for the rest.

If semi-actuated control during coordination is desired, a call to non-actuation can be placed on the phase. This also may be called by a time clock.

Qualitative Summary

The following list summarizes the benefits of fully actuated over semi-actuated signals in a coordinated system:

1. Variable mainline bandwidths to correspond to traffic flows.

2. Dilemma zone protection for mainline traffic.

3. Reduced side street delay in periods of low mainline demand.

4. Free-run operation with variable mainline phase lengths.

The ability to change in the future is difficult to value, but must still be considered. Placing detection on the mainline during initial construction allows future flexibility for full or semi-actuated operation as well as for free-run during off-peak hours. If loops are not placed during initial construction, later installation will involve construction under traffic, with additional maintenance of traffic, and construction costs. It is highly desirable that mainline detection be constructed as part of other signal modifications or roadway construction.

Quantitative Comparison

While the qualitative comparison lends a strong argument for using full detection in all cases, the costs involved are substantial. A literature review produced no quantitative research into the topic. Some articles did very briefly address the topic, but provided no hard evidence. A brief, non - statistically valid survey of traffic engineers and signal suppliers provided a range of responses, from a large proportion not knowing that it is possible to have mainline detection and coordination, to trying it and not liking it, to recommending it. No one provided hard data to support their position.

Research

To address the issue of quantifying and verifying the above discussion, research was performed using Traf-Netsim, a microscopic simulation tool. Version 3.05 was released early with a warning that it was not official, and had some problems to be corrected. During the research, some problems that played directly in the results of some test cases were encountered. Using the two animation programs, Static Netsim and Animated Netsim Graphics, several problems were identified and worked around. No other output format could replicate this information.

Traffic flows were simplistic at first to exaggerate the results. Turns were eliminated to increase the platoon density. While this is unrealistic, it provided a case where if the theory failed, it had little chance.

The main case study involved two-way traffic on both the mainline and side streets. Unprotected left turn phases were modeled at all intersections. Several different traffic flows and timing patterns were analyzed.

A minor case study was made of three parallel arterials forming a grid system. The three arterials were similar to the single arterial and were spaced at 300 ft. ± (100 meters).

Some cases had timings developed especially for the traffic volumes, while others used generic timings, or timings developed for another case. This was done to check the flexibility of the systems to handle differing conditions. While in theory, each different flow pattern should have its appropriate timing pattern; many systems are limited to 1 - 3 timings patterns selected on a time of day basis. These patterns may not have updated for years in some cases, or may not account for seasonal variations. Equipment may also constrain pattern development and selection.

Microsoft's Excel (Spreadsheet) was valuable in analyzing the data. Traf-Netsim provides a large variety and quantity of data, but not in the format needed. Using Excel, the output data file (ASCII format) could be read and parsed into cells that Excel could manage. Excel then sorted the data to group information on the signalized intersections. The information was further sorted to compare total, mainline, and side street performance. It was in comparing the side street information that the benefits really showed a difference. This information would have been very tedious to get using manual methods.

Results

The arterial results support the qualitatively drawn conclusions. Overall delay for the fully actuated systems averaged about 14% less than the semi-actuated. The highest delays involved pretimed signals timed for pedestrians. The levels were almost 50% higher than in pretimed systems without pedestrian timings.

The most compelling reason to use fully actuated systems on arterials comes in the issue of equity. Semi-actuated signals benefit the mainline traffic at the expense of the side street. This issue was brought out in the research. On fully actuated systems, the difference averaged less than a second per vehicle, however, on semi-actuated systems the difference was over 25 seconds per vehicle.

Average Delay On An Arterial Seconds Per Vehicle				
	Pretimed With Pedestrian Timings	Pretimed Without Pedestrian Timings	Semi-Actuated	Fully Actuated
Total	42	28	31	27
Mainline	56	29	23	27
Side Street	17	27	48	27
Equity Difference	39	2	25	0

The most noticeable reason for the differences came in watching the animation program. Under light mainline conditions, the side street received the green earlier, was less likely to force off, and therefore had less delay in the fully actuated system. Under extremely heavy demand, force-offs were often encountered. This lead to a system that acted similar to a pretimed system under heavy demand.

With the semi-actuated system, time was added to the front of the platoon. Vehicles stopped at the stopline were given a head start in front of the platoon. There was then a gap with little traffic using the green until the platoon arrived at the intersection. The end of the platoon was then cut off and had to wait till the next cycle. With the full actuated system, the bandwidth was delayed by ending the mainline green later, and forcing the side street to end (gapout or force-off) later. While the side street received about the same amount of time and therefore the same amount of delay, the number of stops on the mainline was reduced.

The difference between pretimed and fully or semi-actuated signal systems was the pretimed system held the green on the side street till just before the coordinated green, where the actuated systems gapped out. If a side street flow had a gap just larger than the passage time, the actuated signal gapped out, while the pretimed held the green for the second half of the platoon. Traffic, therefore, does not build up as much during the red for the pretimed signals as for the fully or semi-actuated signals. The net result was the semi-actuated provided less green time under most cases. The fully actuated signal adjusted by gapping out the mainline early and providing more time to the side street, if the mainline traffic was light enough.

Grids have been traditionally an area for pretimed signals. The research into grids did not evaluate normal CBD grids with 500 ± ft. (150 meter) spacing, but instead looked at closely spaced parallel arterials. The results, however, backed up traditional wisdom. The lowest average delay was with the pretimed signals without pedestrian timings. Adding the pedestrian timings only increase the average delay by 0.4 seconds per vehicle. The fully actuated signal system was also very close with less than one second per vehicle difference between it and the pretimed. The semi-actuated system, however, had thirty percent more delay than the pretimed signal system.

In comparing timing plans specifically developed for the flows compared to nonspecific plans, there was less sensitivity than expected. Initially, timing plans for the actuated and semi-actuated systems were generated by placing the force-offs at the pretimed beginning of yellows. This worked well for the fully actuated, but not for the semi-actuated. The specifically developed semi-actuated plans were modified to by moving forward the yield point about 10% of the cycle (6 of 60 seconds). This yielded much better results than the initial plans.

In reviewing how the semi-actuate signal works, the reason become clear. If the mainline yields at the same time as the pretimed signal would, then the semi-actuated signal can receive the pretimed side streets green as its maximum green. If the semi-actuated signal gaps out on one cycle, it then has a longer red time to develop a queue, but no longer to relieve it. The semi-actuated signal's side street green will average less than the pretimed's.

Specific vs. Non-specific Timings Average Delay per Vehicle				
	Pretimed With Pedestrian Timings	Pretimed Without Pedestrian Timings	Semi-Actuated	Fully Actuated
Specific	NA	27	31	27
Non-specific	NA	30	32	27

This table should be taken with great caution. As can be seen by looking closely at the numbers, the semi-actuated did better with random settings than specific. It is because of differences in the number of cases and trips analyzed. To compare the two rows in the above table is to compare apples and oranges. It is not a fair comparison. It is a fair to compare cells within a row. In both rows, the semi-actuated signal had the worst results. In the first row, the pretimed and fully actuated signals performed in a similar fashion. (The fully actuated performed two percent better in terms of delay and move more trips. The numbers are rounded off.)

The fully actuated signal system was best in most cases, and on average. The pretimed without pedestrian timings systems performed better than the semi-actuated systems. As expected, the pretimed with pedestrian timings performed the worst.

Two seconds difference on average may not seem like allot, but can add up. If multiplied by 50,000 vehicle per day with an average occupancy of 1.2, it adds up to 12,000 hours per year. At a value of minimum wage of $4.35 for person hours delayed, it equals over $50,000 per year.

Costs

These benefits must be weighed against the additional cost. In Indiana, the additional costs would be for approximately 650 lft of conduit, 2 - 6 loops, 2 - 4 detector housing, 2 - 4 hand holes, 2 - 6 loop amplifiers, 1000 ft of lead-in wire, and maintenance costs. The initial construction costs could vary from $10,000 to $25,000 per intersection. This represents 20 - 30% of the total signal construction costs. Maintenance costs can vary widely and are not discussed here. There are no significant differences in operating costs.

Conclusion

This paper applies to the coordination effects of the two types of detection. Pretimed systems with and without pedestrian timings were also analyzed for a basis of comparison to check for errors in the coordination parameters. No attempt was made at quantifying the non-coordinated benefits. There are several other articles that address full versus partial detection on an isolated basis. Benefits noted in the qualitative comparison provided a basis for the assumptions that started this investigation.

While the data is not conclusive due to insufficient quantity, fully actuated signals should be considered for use in systems. The pretimed systems without pedestrian timings results indicate these systems also should be considered.

The real benefit to fully actuated systems may be in their insensitivity to timing plans. While pretimed systems can produce good results, they should be updated regularly. Where funding is tight for staff to maintain timings, it may be better to have a more forgiving system. The issue of where the funding for staff versus capital expenditure comes from should be considered also.

One of the main goals of the study was to inform traffic engineers and planners that mainline detection with coordination is possible, and can be beneficial. While this study is only a starting point, it does point out the possibilities. Many more case studies similar those performed here and actual field data collection are necessary. Many case studies will be researched after this article goes to print. Field studies also may be conducted. The data and results will be presented at the 1993 ITE Annual International Meeting.

The author encourages others with qualitative or quantitative information to contact him. Inquires are also welcome.