

A Method for Estimating the Useful Lifespan of a Traffic Signalization Plan

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Abstract: This paper address the problem of determining the beneficial lifespan of a signal timing plan for a sizeable traffic network. A procedure is developed and tested that first ages traffic counts and then evaluates optimal network performance at different ages. The procedure overcomes problems with previous work on this subject by applying forecasted deterministic and random variations to origin-destination (OD) flows, which are found by synthetically creating an OD flow table from turning movement counts on the network. The procedure is tested on TRANSYT-7F networks in Milwaukee. It was found that the procedure works well, that many separate simulations are required to test enough random scenarios and that different networks have different lifespans for their signal timing plans.

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INTRODUCTION AND BACKGROUND

Optimizing traffic signalization with computer programs such as TRANSYT-7F and Synchro have become part of routine traffic engineering duties in many locales. Signals are optimized to a specific pattern of traffic volumes and turning movements. As volumes change over time, either within a peak period on a single day or across weeks or months, the traffic system's performance deteriorates. After a certain lifespan signals must be reoptimized to restore the system back to its best possible levels of service. A major uncertainty is the length of the lifespan of the signalization plan. The lifespan can be determined precisely only by recollecting all necessary traffic data at some point in the future and then performing the optimization again. Unfortunately, if complete data must be collected to know the lifespan, then there can never be much of an economic advantage to determining what that lifespan might be.

Ideally, traffic engineers interested in maintaining optimized traffic flow should anticipate well in advance when their timing plans are too old. Since uncertainty exists in any traffic forecast, there is also a need for a traffic engineer to understand the amount of stochastic variation in future traffic volumes and how that variation affects timing plans. This paper offers and tests a procedure to provide such information to a traffic engineer at the point in time that the signal plan is originally created. This procedure exploits recent developments in the subject of forecasting short-term traffic changes within a "window", that is a small portion of a full urban network (1).

Previous Studies

In spite of major differences in traffic systems, some traffic engineers have endeavored to create rules of thumb for the lifespan of signalization plans by trading-off the costs of reoptimization against the costs of poor performance (such as excessive delays) to highway users. Critical to such efforts is knowledge of how quickly traffic data ages. Studies to date have focused on the long-term aging problem, although the short-term problem (traffic variations across a single peak period, which would affect signal timing within a real-time, traffic-responsive system) should be conceptually similar.

One of the primary studies concerning updating pretimed traffic signals was done by Bell and Bretherton (2) in 1986. After assigning a series of random and uniform variations to total link flow and turning flow input of a hypothetical network, and after collecting data for a real network (old and new traffic counts), it was found using Transyt 8 (UK version) that variation of flow has a significant effect on networks. Moreover it was found that the pretimed signal control plans should be updated every few years. It was reported that the performance of the pretimed traffic signal systems would degrade at a rate of around 3 percent each year in the real world. However the data was thought to be accurate for ± 0.5 years, using the traffic count method. This research was done with some

limitations, such as non-conservative flow between intersections and small flow variations. To demonstrate the need to use real networks instead of hypothetical networks, a comparison was done, and the results showed much larger variation on links in reality than in theory.

Federal Highway Administration (FHWA) (3) also confirmed the benefits of updating fixed signal controlled systems. It was reported that updating coordinated traffic signal timing plans may benefit a system with a 12 percent reduction in travel time.

A survey on traffic signal timing improvement practices was presented in the National Cooperative Highway Research Program report number 172 (4). The survey's purpose was to determine optimum timing intervals for signal reoptimization. It was recommended theoretically that the best period for a reoptimization to take place would be between one to three years.

Stevanovic and Martin (5) investigated the concept of aging on hypothetical traffic signal timing plans, using Synchro and SimTraffic as the optimization-simulation tools. The benefit of updating a timing plan was presented by the ratio of reduction in performance index (delay time and stops) between an updated timing plan and an old timing plan after a certain change in traffic flow. The relation between aging and updating timing plans was evaluated by applying specific increasing and decreasing uniform changes (5%, 10%, 15%, 20% and 25%) to input turning movements and by applying stochastic traffic changes to turning movements on a nine-node hypothetical grid network.

Swayampakala and Graham (6) tried to determine the optimum timeframe for signals to be retimed, taking into consideration the relation between financial costs of retiming and economic loss due to delay. The data for this study was available from transportation agencies for at least five to seven years, which was then interpolated into smaller time periods. Signal delays were estimated and optimized using Synchro. The results of this study showed that the retiming period depends on the rate of variation in traffic volumes. This study focused on retiming isolated intersections, which eliminated the need for conservation of flow in the models.

Another project concerning isolated intersections by Park and Agbolosu-Amison was sponsored by the Virginia Department of Transportation (7). OptQuest and the Platoon Dispersion Model (ISAPD) were used to evaluate the performance of a traffic signal. Archived data from the Virginia Department of Transportation for 13 isolated signalized intersections were used as the base case, with an ISAPD-OptQuest optimized timing plan for the same year. Different scenarios for reoptimization intervals were generated, such as detecting traffic for 2 weeks, 4 weeks, etc. The results of this project showed that the performance of the base-case timing plan degraded linearly over time, and that the time interval of one year was the best for reoptimization of traffic timing plans for isolated intersections.

Discussion

Previous work in determining the lifespan of a signal timing plan is of mixed success. Previous studies disagree on the lifespan of a plan, so it is safe to conclude that lifespans differ across traffic networks. Methods that use a history of traffic data largely avoided issues relating to conservation of flow, but seem to be limited to small networks and cannot lead to a forecasting methodology. Methods that apply stochastic changes directly to turning movements are burdened with inconsistent flows, so they are limited to testing only small variations and that might be associated with traffic in the near future.

Surprisingly, nobody has seriously discussed techniques of traffic forecasting as means to determine how fast traffic data ages. Although such techniques may be difficult to apply, they can overcome some of the problems encountered by previous investigators. However, the currently available traffic forecasting models, with the possible exception of TRANSIMS from FHWA that is still undergoing testing, are deterministic and are thought to be insensitive to the types of traffic changes that would naturally occur within the one- or two-year lifespan of a typical signal plan.

PROCEDURE FOR DETERMINING LIFESPAN

The procedure developed for this paper is a direct outgrowth of the authors' attempts to use some of the fairly simplistic methods that were seen in the literature to analyze many different possible lifespans of signal time plans. These methods applied deterministic and random disturbances directly to traffic counts and to certain other inputs needed by the traffic optimization software. These simplistic methods seemed to work well for very small

disturbances, because the optimization software had some resilience against a lack of consistency between upstream and downstream flows. However, larger disturbances that might be associated with longer durations between reoptimizations resulted in warnings from the software and implausible results. Consequently, the existing methods could not investigate whether a signal plan had a particularly long anticipated lifespan, so a better, more rigorous procedure was needed that could work for all possible lifespans.

This research adopts the same definition of lifespan as found in past studies, but concentrates on only one part of the lifespan calculation – travel time savings as determined by traffic operations software. Recognizing that there are other factors in the calculation of lifespan, a signal plan should survive until the user-benefits of a reoptimization clearly exceed the costs of performing the reoptimization. Since the cost of performing the reoptimization is roughly constant over time for any given network, the life span depends almost entirely on the amount of user-benefits, which mostly increase in time and are dominated by travel time savings. The costs of reoptimization can be quite large or quite small depending upon local circumstances.

A customized estimation of the lifespan of a signalization plan inherently uses the concepts of traffic forecasting and extensive use of error theory. This paper specifically uses two important techniques from the traffic forecasting: traffic assignment; and synthetic origin-destination flow estimation from traffic counts. These techniques allow for stochastic variations in traffic that do not cause a violation of conservation of flow through and between intersections.

Figure 1 is a flow diagram of the major steps in the procedure for investigating the benefits of reoptimization after a specific period of time. Each step can be executed with varying degrees of sophistication. This paper tries to use the simplest level of sophistication in an attempt to produce the simplest procedure, overall.

It is readily seen that this procedure differs substantially from the methods used in previous studies that applied random disturbances directly to volumes and turning movements. This procedure, instead, applies random disturbances to origin-destination (OD) flows. There are two problems, in particular, that arise when working with OD flows. First, it is prohibitively expensive to observe OD flows in the field, so they must be somehow synthesized using statistical methods. Second, the amount of variation over time in an OD flow is unknown.

The procedure recognizes that the future is unknowable, although there are trends to traffic growth (or decline). Thus, there is a need to generate several random future traffic scenarios at any given age. Testing many random scenarios allows for a good calculation of average benefits of reoptimization, but it can also lead to an assessment of worst case conditions.

Monte Carlo techniques are also employed in determining the relationships between random variations in turning movements and random variations in OD flows. These relationships are highly dependent on the peculiarities of each network, particularly network topology and the location of entry and exit points, so the relationship must be custom determined each time it is needed.

Once turning movements are obtained from a traffic assignment the evaluation progresses just as outlined by previous authors.

Particularly unusual aspects of the procedure are two steps that are essentially executed backwards from how they would normally be seen in professional practice. In particular, the OD flow table estimation problem is the inverse of the traffic assignment problem. Estimating errors in OD table flows is the inverse of the error propagation problem of a traffic assignment.

Since each step could be accomplished in a variety of ways, the steps are illustrated by four networks from the City of Milwaukee. These networks do not have any topographic or geometric features or levels of traffic that would be unusual in any other city, so they serve well as good test cases for the methodology.

MILWAUKEE CASE STUDIES

The City of Milwaukee provided four preexisting networks for these case studies, actually consisting of two locations each at two different times of day. Milwaukee uses TRANSYT-7F for its signal optimization, so TRANSYT-7F was selected for these case studies as a matter of convenience. To avoid investigator bias in the preparation of data, most data and software settings were left intact from those provided by the City of Milwaukee. The only changes were in the values of link flow and turning movements, as dictated by the procedure. These

networks were developed by very experienced traffic engineers at the City of Milwaukee, and no coding errors or other anomalies were detected the research team. Networks are referred to here as Lisbon (am or pm) and Lincoln (am or pm). Both Lisbon networks had 23 intersections and both Lincoln networks had 18 intersections. Milwaukee's street system is mostly a grid, but Lisbon Ave. is a diagonal street, so its network, unlike the one for Lincoln, does not exhibit a regular pattern. Both networks have cross streets, so there are multiple ways to go between many of the origins and destinations. These networks were deemed big enough to reveal any problems with the procedure.

Unfortunately for our purposes, City of Milwaukee does not collect enough turning movement data at sufficiently regularly occurring intervals for us to determine the extent of random variations over time. Such a dataset would necessarily contain frequent turning movement counts at many intersections; cities that are worried about the costs of reoptimization would probably not have access to such comprehensive data. A good model of turning movement variation was not found in the literature, and a cursory search of similar sized cities in the upper Midwest did not uncover a data set of sufficient detail and depth. Thus, the authors made a strategic decision to look elsewhere and were able to locate a suitable dataset in Tallahassee, FL. With the knowledge that transferability is an issue, the formulated model of turning movement variations specifically recognizes that different cities have different overall growth rates. For the case studies, traffic growth rates within the turning movement model were modified to better match Milwaukee experience.

TRANSYT-7F does not possess the ability to estimate OD flow tables or to perform a traffic assignment. These tasks were given to the Quick Response System II (QRS II) software package. It was therefore necessary to build QRS II networks that exactly match their corresponding TRANSYT-7F networks. Figure 2 shows the two Lincoln-am networks side-by-side. The QRS II network seems to contain many more links, because TRANSYT-7F defines each turning movement at an approach to be a separate "link" but does not actually show all of the "links" graphically. TRANSYT-7F also requires information on upstream "feeders", which are equivalent to "turning movements" in QRS II's version of each network. An interface program was written to transfer all the relevant traffic assignment results from QRS II to TRANSYT-7F. The QRS II network in Figure 2 also shows all the places where traffic enters and exits (origins and destinations, respectively). There are 36 such locations in each Lincoln network and 35 such locations in each Lisbon network.

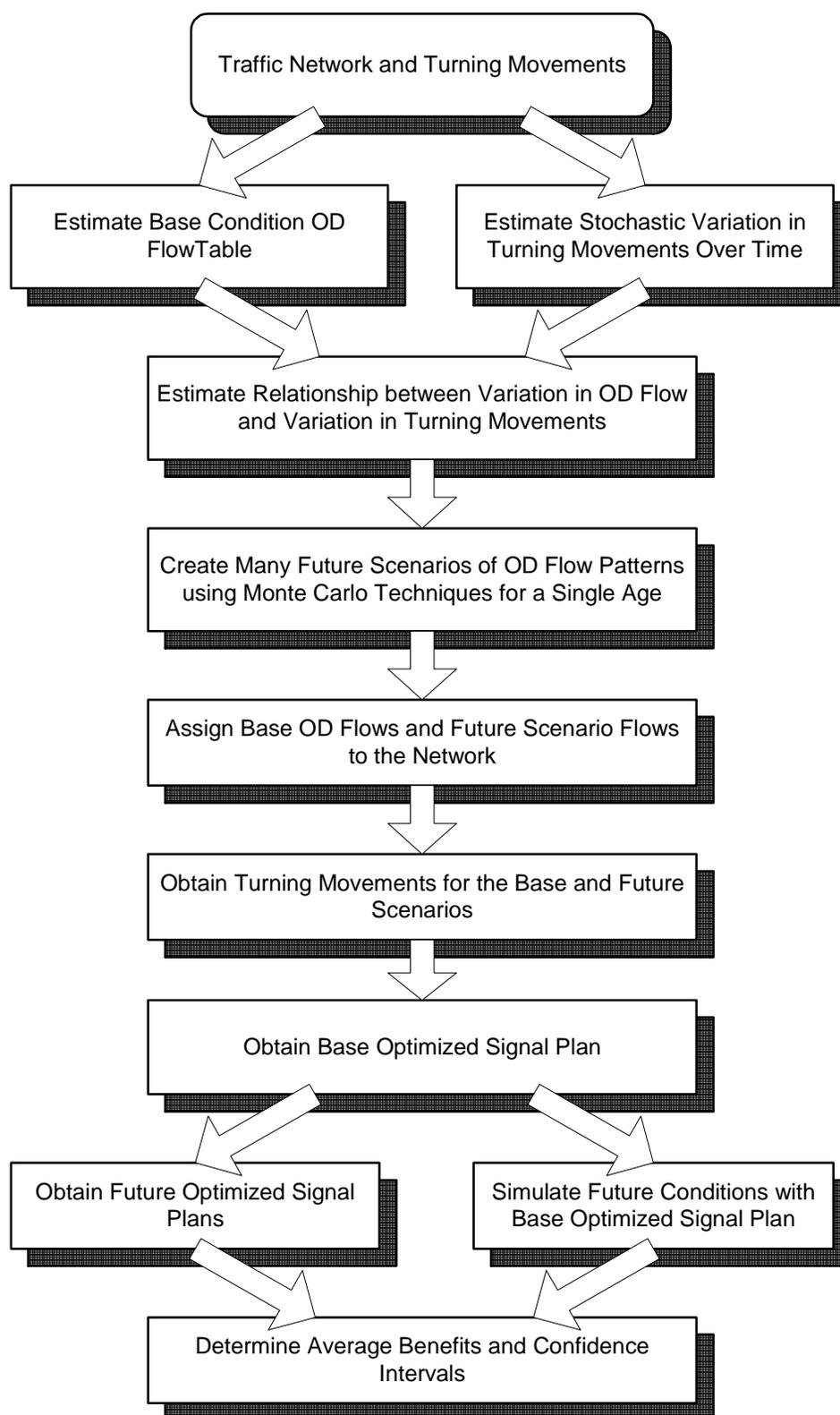


FIGURE 1 Major Steps in Forecasting the Lifespan of a Signalization Plan

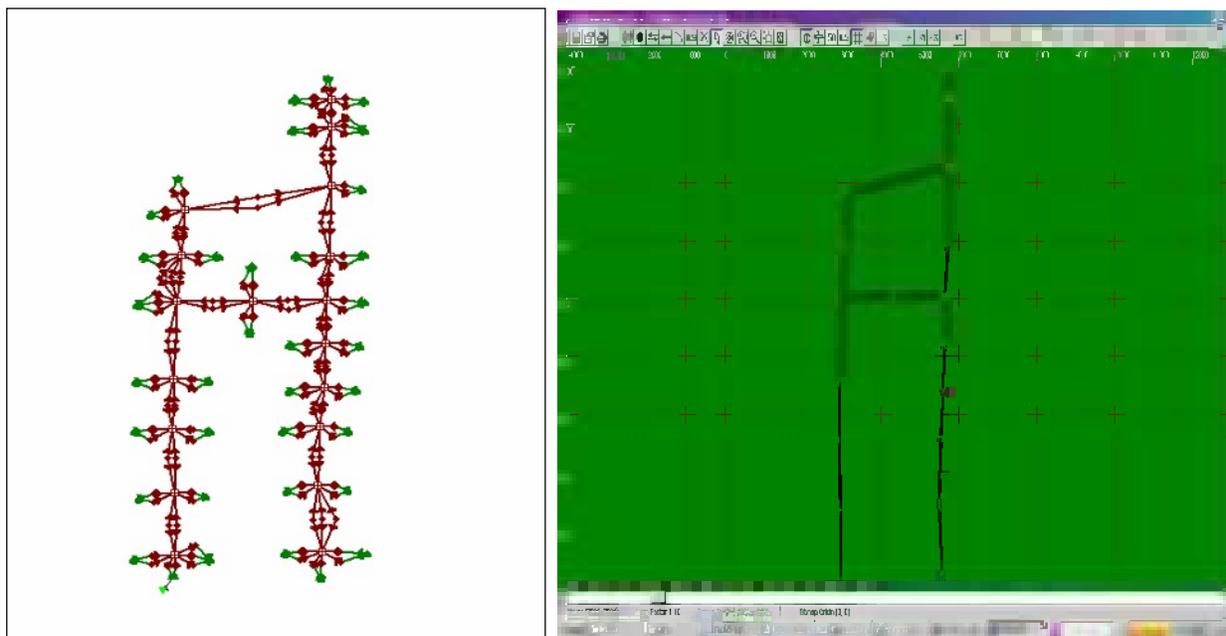


Figure 2 Lincoln AM Network as Seen in QRS II (left) and TRANSYT-7F (right)

Estimate Base Condition OD Flow Table

QRS II has several methods for estimating synthetic OD flows from traffic counts. For this study, QRS II's static, generalized least squares method was selected. Usually, a traffic count in OD flow estimation consists of a whole approach volume, but in this study it was possible to fit the OD table to turning movements, which is a much richer source of count information. Data on upstream feeders were not used because much of this data were artificially created by TRANSYT-7F and could not be trusted. Specifically, QRS II was asked to minimize this function, P:

$$\min P = \sum_{a=1}^A w^a \left(V^a - \sum_{i=1}^N \sum_{j=1}^N p_{ij}^a T_{ij} \right)^2 + \sum_{i=1}^N \sum_{j=1}^N z (T_{ij}^* - T_{ij})^2 \quad (1)$$

where V^a is a ground count for link direction a , T_{ij} are the trips between origin i and destination j to be estimated, T_{ij}^* is the seed trip table, p_{ij}^a is the proportion of trips between origin i and destination j that use link direction a (as determined by a traffic assignment), N is the number of zones and w^a and z are weights. Each direction of a two-way link, a , may have a separate ground count and may be considered the same as a "link" when only directional links are present in the network. In these case studies a "link direction" is the same as a turn at an approach. Nonnegativity constraints apply to T_{ij} . See (1) for full explanations of this estimation method and how it might be applied to a traffic "window". Also, see (9) for a comprehensive introduction to the subject of synthetic OD table estimation. All-or-nothing traffic assignment was used throughout the case studies.

Because there are almost always more OD pairs than ground counts, synthetic OD table estimation requires a seed OD table, T_{ij}^* , to ensure that there are more data than parameters to be estimated. Crafting a good seed OD table depends on the problem at hand. In these case studies, recommendations in (1) were followed. Seed OD tables were built that conserved the number of origins and destinations at each entry/exit point and gave approximately correct turning movement percentages across the whole network. Specifically, this equation was used:

$$T_{ij}^* = O_i D_j X_i Y_j F^{-\tau_{ij}} \quad (2)$$

where O_i is the number of origins at entry point i , D_j is the number of destinations at exit point j , τ_{ij} is the least number of turns necessary to travel between entry point i and exit point j , X_i is a balancing factor to assure that origins are conserved at entry point i , Y_j is a balancing factor to assure that destinations are conserved at exit point j , and F is an arbitrarily chosen constant. A value of $F = 2.0$ was used in this study.

Link weights, w^a , were held constant at a value of one, but z was set to a value, iteratively found, such that TRANSYT-7F gave almost exactly the same measures of effectiveness (MOEs) with a traffic assignment of the synthetic OD table as with the original base-case count data. Specifically, z was set such that average speed, total delay and total stops were all held constant plus or minus 10%, which was achieved in all cases. No specific attempt was made to achieve better than a 10% fit to the original MOEs, so as avoid replicating counting errors that are known to be present in such data. At the same time, the RMS errors to the turning movement counts were monitored. These RMS errors in ranged from about 10% of average count values in the Lincoln networks to about 20% in the Lisbon networks, which were about as expected. Had we been unable to get a good agreement with the original Milwaukee MOEs or if the RMS errors in the link counts were seriously wrong, then we would have needed to find a suitable improvement to Equation 2. Only one synthetic OD table was required for each network, as there was no need to perform this step for future scenarios. The Lisbon networks had about 180 turning movement counts and the Lincoln networks had about 150 turning movement counts, both unusually large numbers for networks of these sizes.

Estimate Stochastic Variations in Turning Movements over Time

Random variations in OD flows are not observable in the field, but it is possible to mathematically relate OD flow variations to random changes to link flows and turning movements. Thus, it is first necessary to create a way to forecast the amount of variation in link flows and turning movements at future points in time. Traditional methods of travel forecasting are not particularly helpful in this regard because the time horizon for the forecast is much too close. For these case studies, as in earlier research on this subject, it was assumed that future traffic counts were composed of a linear growth, constant across a whole network, and a random term. That is,

$$V_{(k+t)} = V_k(1 + Gt) + \varepsilon(0, s) \quad (3)$$

where V_k is the turning movement at time k , V_{k+t} is the turning movement at some future time t months from time k , G is a monthly growth rate and $\varepsilon(0, s)$ is a normally distributed random variable with zero mean and a standard deviation of s . The standard deviation, s , is a function of the type of turn and the time from base conditions, t . The random term would account for day-to-day variations in traffic, changes in driver behavior, changes in locations of daily activities and uneven growth in urban development. A normal distribution was suggested by Bell and Bretherton (2). This equation ignores possible correlations between the three turning movements at a single approach, which were reasonably small in the Tallahassee data set (Pearson r 's of between 0.14 and 0.22 after accounting for network-wide growth).

An inspection of the traffic data revealed that the standard deviation, s , depends upon both the time in months, t , and the magnitude of the base count, V_k . After application of probability theory and after some trial and error, the following elementary equation was found to work very well for each type of turn:

$$s = \sqrt{(\alpha V_k)^2 + V_k (\beta t)^2} \quad (4)$$

where α and β are calibrated coefficients. Data from 200 intersections were used to estimate the coefficients. The range of times between counts at a single intersection is from 3 to 68 months. The standard deviation was first calculated across six categories of traffic counts (2 categories of time cross-tabulated against 3 categories of volumes), then the coefficients, α and β , were estimated using nonlinear regression. Table 1 contains the estimated coefficients, which were all statistically significant at the 0.05 confidence level.

TABLE 1 Coefficients for the Standard Deviations of a Turning Movement

Coefficient	Through Movement	Left Turn Movement	Right Turn Movement
α , Volume	0.1460	0.3501	0.3753
β , Time	0.1699	0.2275	0.1323

These coefficients might vary by season, but this hypothesis was not tested. Equation 4 should not be used for times less than 6 months.

Estimate Relationship between Variation in OD Flow and Variations in Turning Movements

The standard deviation of a future count should not be applied directly to turning movements in a TRANSYT-7F model because doing so will violate conservation of flow. TRANSYT-7F is tolerant of small violations, but balks or produces erroneous results if the violations become too severe. Thus, random variations must be applied to base OD flows, as found through the synthetic OD flow estimation process. It is well known among network theorists that there is no simple relationship between errors in OD flows and the errors in the results of a traffic assignment. Thus, the relationship between a turning movement standard deviation and an OD flow standard deviation is not easy to ascertain theoretically and would most certainly vary considerably across networks.

The most straightforward method of determining these relationships is through many Monte Carlo simulations. For each network several series of 10 random OD tables were generated by adding to each OD flow a normally-distributed random number of zero mean and a standard deviation for each series as a fixed percentage of the OD flow. Each OD flow is considered independent of other OD flows. Each OD flow was constrained to be positive. The randomized OD tables were assigned to the network and the standard deviations of the turning movements were observed. Figure 3 illustrates the results for one network, Lisbon-pm.

The nearly proportional relationship seen in Figure 3 is expected from probability theory, due to the adoption of all-or-nothing traffic assignment. For all networks there was a range of three-to-one and a five-to-one ratio between OD flow standard deviation and turning movement standard deviation. These proportional relationships made it easy to find an OD percentage standard deviation that corresponded to a specific lifespan, as ascertained by Equation 4.

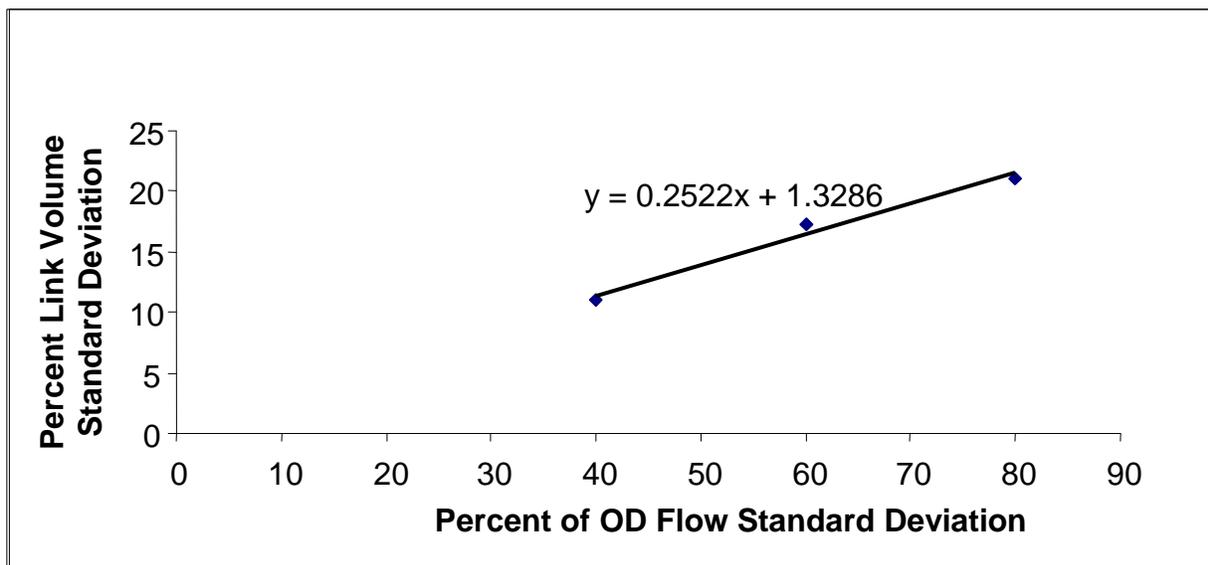


FIGURE 3 Relationship between OD Flow Percent Standard Deviation and Link Volume Percent Standard for the Lisbon-pm Network

Assessing Scenarios

There are many alternative futures for any given lifespan, and a fair number of these should be tested. Again, Monte Carlo techniques can be employed. Each randomized OD flow table at each candidate lifespan for each network is referred to here as a “scenario”. Ideally, many scenarios should be run in order to test both average and worst case conditions, but we limited the case studies to just three OD flow tables for each lifespan for each network. A separate TRANSYT-7F network must be created for each OD flow table.

From this point forward, the procedure is the same as outlined by earlier authors:

- Obtain an optimal signal plan by using the base-case ($t = 0$) network;
- Simulate the network with future volumes and turning movements, but lock in the base-case signal plan;
- Reoptimize the network with future volumes and turning movements; and
- Observe the differences between the simulation and optimization.

This procedure is repeated for each scenario; the results for the scenarios of the same network and lifespan are averaged; and the best lifespan is chosen.

Representative Results

The constant growth rate, G , should be chosen on the bases of historical data or existing traffic forecasts. For the case study results presented here, we selected a cautiously-large growth rate of 0.00167 per month, which corresponds to a 2% growth in traffic per year. The growth for individual link flows could be bigger or smaller, depending upon the Monte Carlo randomization. Other conditions of the tests are briefly as follows.

- TRANSYT-7F's "hill climb" method was selected for optimization because of the way the City of Milwaukee had prepared the networks.
- Cycle length, offsets and splits were used as optimization parameters. Since phase sequence cannot be used with the hill climb method, it was ignored.
- The objective function was set to minimize total control delay. This objective was chosen according to the research done by Min- Tang Li and Albert C. Gan (10).
- A range of 90 to 150 seconds cycle length with an increment of 10 seconds was used. This specification was limited to a 90 second minimum cycle length due to safety and larger-system considerations dictated by the City of Milwaukee.
- There was a minimum volume of 10 vehicles for any link volume or upstream feeder due to TRANSYT-7F limitations.

It is important to recognize that the quality of the signal plan depends on the software settings; and therefore, the before-to-after changes in delay will be affected by these settings. There are many setting changes that could lead to greater improvements in delay, but making these changes would have substituted the judgment of the authors for the judgment of the staff at the City of Milwaukee.

Table 2 illustrates the results for the Lincoln-am network when TRANSYT-7F was told to optimize total control delay for the network. The table gives the results for each of three scenarios for ages of six to 24 months. The key numbers in this table are the average differences between the simulated and optimized delays. Scenarios at the same age are seen to produce considerably different delays in TRANSYT-7F. The average difference in delay is seen to be about constant up to 12 months, jumping slightly at 18 months and increasing markedly at 24 months.

The Lincoln-pm and the Lisbon-pm networks behaved similarly to the Lincoln-am network, except that the delay differences were slightly smaller at 24 months than at 18 months. This anomalous result could be due random variations of turning movements at saturated intersections. Lisbon-am network showed comparatively little difference between the simulated and optimized networks at any age, likely due to restrictions on optimization parameters imposed by the City of Milwaukee.

TABLE 2 Control Delay (Vehicle-Hours/Hour) in TRANSYT-7F for Lincoln-am

Age of Plan		Simulated Delay	Optimized Delay	Difference
6 Months	Scenario 1	148.3	116.1	27.7
	Scenario 2	113.0	100.0	13.0
	Scenario 3	121.6	111.4	9.2
	Average	127.6	109.2	16.9
12 Months	Scenario 1	132.2	106.3	24.4
	Scenario 2	140.0	117.3	19.4
	Scenario 3	151.2	129.9	16.4
	Average	141.1	117.8	19.8
18 months	Scenario 1	173.5	118.3	46.7
	Scenario 2	215.4	149.7	43.9
	Scenario 3	185.6	137.2	35.3
	Average	191.5	135.1	41.8
24 Months	Scenario 1	183.5	112.4	63.3
	Scenario 2	344.3	149.5	130.3
	Scenario 3	292.5	150.8	94.0
	Average	273.4	137.6	98.8

Discussion

There are many possible improvements to the procedure, although there is little indication from the Milwaukee case studies that those improvements would be particularly beneficial. However, these improvements could include:

- Equilibrium or multipath traffic assignment, both for creating a synthetic OD flow table and for assigning OD flow tables to networks;
- Consideration of diversion of vehicles around saturated sections of the network;
- Seasonal adjustments to growth rates and/or standard deviations;
- Dynamic traffic assignment to see the effects of traffic variations within a peak period; and
- Consideration of the dependence of turning movements at the same approach, perhaps by recognizing that there is dependence between OD flows that have either the same origin or the same destination.

The procedure could be applied to very short lifespans (i.e., 5 to 30 minutes) that would be required for real-time traffic control, with appropriate modifications to growth rates and standard deviations.

Because of the use of two very different software packages, the procedure as executed in this paper was tedious. However, there no reason why the whole procedure could not be automated, such that the lifespan of a signal plan could be easily estimated at the time that the signal plan is first created.

The method of judging the goodness of fit of the OD flows, deviations from major MOEs, was somewhat arbitrary and was chosen here to be consistent with the optimization criteria for TRANSYT-7F. In the absence of an existing OD flow table, which is typical, the quality of the estimated OD flow table needs to be assessed through such proxies. More experience with the procedure will be required to determine which MOEs or other outputs are best suited for validating the quality of the OD flows.

Equation 4 suggests that there are random variations in turning counts at very small ages, just due to day-to-day variations in traffic. Therefore, a pretimed signal plan will perform less than optimally immediately after it is implemented. There would be little advantage to reoptimization unless the potential improvements in delay (and other measures of user-benefits) are significantly better than would be achievable at small ages (e.g., six months). For example, it is obvious that the control delay at an age of 12 months in the Lincoln-am network (Table 2) is not significantly different from 6 months. Thus, one could argue that reoptimization should not proceed until at least an age of 18 months, just on statistical grounds.

The procedure does not depend upon any particular piece of software for signal plan optimization. It is entirely possible that there are other software products that will provide better estimates of delay, before and after reoptimization, than TRANSYT-7F. For example, microsimulation might be a more precise way of assessing user-benefits once the timing plan is established. However, it is essential that the software be sufficiently fast to accommodate all of the required runs in a reasonable amount of computation time.

CONCLUSIONS

The purpose of this study was to develop a procedure for estimating the best lifespan for a signal timing plan, such that the procedure can be implemented at the same moment that the signal plan is first developed. The research diverges from previous studies that developed rules of thumb for a lifespan.

In reality traffic varies due to many reasons, such as population growth, economic growth, land use development, spot congestion and driver behavior. Much of this cannot be accurately predicted. A traffic aging model must account for how both deterministic and seemingly random changes in vehicular flow occur over time.

Aging link volumes and turning movements directly can cause serious violations of conservation of flow on networks. However, applying random changes to OD flows guarantees conservation of flow. Fortunately, software is readily available for synthetically estimating OD flows from traffic counts. It is possible to use the optimization software to verify that the synthetic OD flow table is reasonable for this purpose. This paper demonstrates previous authors were too pessimistic about the complexity of achieving conservation of flow when testing long lifespans.

Preexisting networks from the City of Milwaukee were used to implement the procedure; these networks consist of numerous pretimed coordinated intersections. After simulating and optimizing the networks using TRANSYT-7F and according to policies of the City of Milwaukee, it was found that the lifespan for a pretimed signal plan differs according to the network. There is no unique timeframe for reconsidering the optimization process. In addition, there is a tendency for the benefits of reoptimization to plateau after a period of time. Each network should be checked for its reoptimization lifespan separately, taking into consideration all of its characteristics, while analyzing all aspects that would affect the decision, such as the costs of data collection and software implementation.

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