Progression-Based Optimization Model in TRANSYT-7F

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The forward progression opportunities (PROS) concept has been developed as an alternative for design and evaluation of arterial signal timing. The concept expands upon the maximal bandwidth approach by considering time-space progression opportunities that do not necessarily extend throughout the length of the route. Further, PROS can be available for traffic outside the through bands of the traditional time-space diagram. PROS can be used alone or in conjunction with system disutility measures (such as stops, delay, and fuel consumption) for a more complete progression design. The implementation of the PROS concept for application on multiple arteries within networks, using TRANSYT-7F, is presented. Data are presented to demonstrate the performance of the model relative to other optimization strategies. Experiments with the model indicate that it can produce significant improvements over both the traditional bandwidth and disutility methods for designing arterial and network signal timing plans.

Optimizing traffic signal timing is one of the most cost-effective ways of improving the quality of traffic flow and reducing fuel consumption (*1*). There are two basic approaches for off-line optimization of progressive signal system timing: (a) maximizing bandwidth efficiency, and (b) minimizing a disutility index that has generally been a function of a combination of delay, stops, fuel consumption, and sometimes queue spillover.

The first approach has traditionally been appropriate only for arterial streets and includes models such as PASSER II (*2*) and MAXBAND (*3*). MAXBAND has been extended for application to multiarterial networks, but this version is not widely used, primarily because of excessive computer run time and its limitation to mainframe computers (*4*).

The second approach can be used for arterial streets as well as two-dimensional networks; it includes models such as TRANSYT-7F (*5*). TRANSYT-7F is one of the most powerful computer programs for traffic signal timing and traffic flow analysis; however, many traffic engineers prefer bandwidth-based solutions for designing arterial timing plans to ensure perceived progression. Designs based on minimizing disutility may not produce the wide through progression bands. On the other hand, maximal bandwidth solutions do not necessarily result in minimum delay and stops or, more significantly, fuel consumption. This is because these solutions do not explicitly recognize traffic demand as a function of time on individual links. That relationship is only implicit.

Several studies have investigated the benefits of combining the disutility optimization approach and the bandwidth optimization approach. One approach was to use maximal bandwidth optimization models such as PASSER II and MAXBAND to develop initial timing plans for TRANSYT-7F (*6*–*8*). Chang et al. used an estimate of link delays to determine the directional bandwidth ratio (*9*). Cohen and Liu developed an approach that constrains the TRANSYT-7F optimization to preserve the band computed by a maximal bandwidth program (*10*). Gartner et al. developed a method that generates a variable bandwidth progression in which each through link can obtain an individually weighted bandwidth (*11*). Both volume and saturation flow rates on a through link were used to obtain the link weight.

It was also attempted to give more priority to the arterial links in a TRANSYT-7F optimization. TRANSYT documentation has suggested the use of link-to-link flow weighting, stop weighting factors, and delay weighting factors to ensure time-space progression (*5*,*12*). Moskaluk and Parsonson suggested absolute prioritization of arterial through links while controlling minor movement performance degradation by specifying a maximum degree of saturation for these movements (*13*).

All of these approaches have been simple manipulations of the model's inherent capabilities, which can be replicated through data coding. None has resolved the fundamental need to combine the *modeling* of progression explicitly in TRANSYT or to combine a progression-based objective with disutility.

Wallace (*14*) and Courage (*15*) developed the forward progression opportunities (PROS) model as an alternative design and evaluation approach for traffic progression. This model considers not only the through bands, but also short-term progression opportunities within the system. The concept of forward progression opportunities simply recognizes the ability to travel through two or more adjacent intersections at the desired progression speed without stopping. When such opportunities are obtained, both in time and space, a disaggregate measure of progression is available that is much more flexible than traditional through bands. Traditional through bands are severely bounded by absolute physical rules. PROS are less constrained.

When PROS are optimized solely, the problem experienced by Moskaluk and Parsonson exists—minor (generally cross-street) movements may be driven to their minima in an optimization. To overcome this, an extension of the PROS concept was developed to maximize a combinational objective function of PROS and the TRANSYT-7F disutility index (DI). In the past the TRANSYT objective function has been a performance index (PI), which was a function of stops and delay and was always minimized. This is commonly referred to as performance optimization. The current model uses new definitions of objective functions (*16*). The older stops and delay function is now referred to consistently as the DI. The com-

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binational objective function, defined as PROS/DI, combines the benefits of the two design approaches. An early experimental version of the TRANSYT model was modified to implement the PROS model. Experience with this model (*14*) suggested that the concept had merit.

Recently, the PROS model was incorporated into TRANSYT-7F, Release 7. The basic principle of using PROS and, more significantly, PROS/DI as an objective function in TRANSYT-7F remains the same. However, other improvements and new features were added. These improvements include extending the PROS concept for application to multiarterial networks, allowing a cycle range evaluation, adjusting timing to reduce the DI in a simple PROS optimization, using PROS-versus-DI weighting, and employing PROS directional weightings for individual arteries.

Other general improvements to TRANSYT-7F that support this are important, but they are not reported explicitly herein. In short, they include

- Improved modeling of stops at degrees of saturation near or over 100 percent,
- Better split optimization based on degrees of saturation, and
- Explicit handling of overlap phases.

This paper describes the incorporation of the PROS concept into TRANSYT-7F and investigates the results obtained using the model.

TRANSYT-7F MODEL

The Traffic Network Study Tool (TRANSYT) model was originally developed by Dennis I. Robertson in England (*17*). Since the development of the original model, many improvements have been made in Great Britain, the United States, and elsewhere. TRANSYT has been extensively tested and used throughout the world for design and evaluation of traffic signal timing. The model most widely used in the United States is TRANSYT-7F; its latest version is Release 7, into which the PROS model discussed in this paper was incorporated.

TRANSYT consists of two main parts:

1. A traffic flow model that is a deterministic macroscopic time-scan simulation. It simulates traffic flow in a street network of signalized intersections to compute a disutility index for a given signal timing plan.
2. An optimization procedure based on an iterative gradient search technique, known as hill-climbing, makes changes to the signal timing (offsets and splits) to determine whether or not the PI is improved. By adopting only those changes that improve the PI, the optimizer tries to find a set of timing that optimizes the PI, subject to any limits placed on the process.

These submodels are inexorably intertwined in TRANSYT-7F—particularly in the new version, which has considerably more complex traffic simulation and optimization models.

PROGRESSION OPPORTUNITIES CONCEPT

A forward progression opportunity is defined as the ability presented at a given point in time to enter one intersection on green (including the change period) and expect to travel through the next downstream intersection without stopping, independent of other traffic.

Each such opportunity available during a given period of time (for example, a "step" in TRANSYT-7F) is tabulated as one progression opportunity. Multiple opportunities, both in time and space, are accumulated as PROS.

The number of PROS in a given direction for a given time period (or step) is the number of successive green signals that will be encountered at the design speed without stopping. The aggregate PROS is found by summing the PROS over all time periods in both directions, or

$$\text{PROS} = \sum_{k=1}^{2} \sum_{j=1}^{N} \sum_{t=1}^{C} \text{PROS}_{kjt} \qquad (1)$$

where

k = direction of travel;
j = intersection number, of which there are N; and
t = time in units common to the model, up to the cycle length, C.

A subset of the above is to consider only the PROS_{kjt} where t ranges from T_{kl} to T_{kt} and these limits respectively represent the leading and trailing edges of the arterial through green bands in each direction—for example, from PASSER II. Optimizing this subset would have the effect of explicitly optimizing maximal bandwidth.

Another measure related to the PROS concept is also defined as cycle progression opportunities (CPROS). In the absence of any signal, the full cycle would be available as progression opportunities. This hypothetical measure is obtained for both directions as follows:

$$\text{CPROS} = CN(N - 1) \qquad (2)$$

where the variables are as defined before. The ratio PROS/CPROS, called effective PROS (PROS_e), is analogous to the bandwidth efficiency of PASSER II and MAXBAND. By the nature of this definition, PROS_e will always be less than unity.

MODEL IMPLEMENTATION

The procedure used to optimize signal timing on the basis of PROS or PROS/DI is functionally the same as that used by the TRANSYT-7F model to minimize the normal DI. To implement this model, TRANSYT-7F was modified to calculate, and to optimize optionally, PROS or PROS/DI instead of DI.

Simple PROS Optimization

In a simple PROS optimization, the main objective is to maximize PROS of the arterial through movements. However, to deal with other movements, the model also tries to minimize the DIs elsewhere in the system while not reducing the arterial PROS.

If this option (referred to as "PROS" and "DI") is selected, TRANSYT-7F performs two steps of the traditional hill-climbing procedure as follows:

1. The PI is initially based purely on the $PROS_e$ on the arteries. A change in timing is retained if it increases the $PROS_e$. When computing $PROS_e$ for a multiarterial system, the PROS and CPROS are computed first for each artery using Equations 1 and 2. Then the aggregate PROS and CPROS for the whole system are determined by summing their values over all designated arteries. The $PROS_e$ for the system is determined on the basis of these two values. (The ratio $PROS_e$, rather than the raw value of PROS, is used to allow for a cycle search, because the raw value always increases with cycle length.)
2. In Step 2, the hill-climbing procedure is used to minimize the DI without reducing the $PROS_e$ value achieved in Step 1. This allows for some adjustment of the offsets and splits on the arteries. In addition, the timing for intersections (nodes) not considered in Step 1 (because they are not on any designated artery) are optimized entirely in Step 2.

The model also allows for a cycle search to select the best cycle length within a user-specified range. In this process, only the first step of the optimization can be performed, because there can be only one objective function when different cycles are compared. The comparison is based exclusively on the $PROS_e$ values.

When PROS are optimized in a grid network, the default is to give the same weight to all nodes on all arteries; however, directional weightings can be used to give priority to specific arteries or directions.

As noted before, PROS-only optimization suffers from the same disadvantages as the maximal bandwidth approach in that the actual traffic demand is not explicitly considered. For example, split optimization generally forces the green times of minor movements at nodes where split optimization is permitted to their minima. This is because PROS-only optimization does not provide criteria for setting green times for these movements. One of the following procedures can be used to avoid oversaturating minor movements and ensure an equitable distribution of green times when optimizing the PROS.

1. For pretimed controllers, initial splits that equalize the degrees of saturation can be requested. For actuated controllers, initial splits are automatically calculated to achieve a desired degree of saturation. All splits are then held constant in the first optimization step.
2. The splits can be coded by the user and fixed during the first optimization step. These splits should be calculated externally.

Another problem with simple PROS optimization is that it may cause the PROS to increase in one direction (not necessarily the critical direction) at the expense of the PROS in the other direction. This problem can generally be avoided by using proper directional weightings or by coding initial timings from a maximal bandwidth optimization program.

PROS/DI Optimization

An extension of the PROS concept was developed to redefine the objective function as the PROS/DI ratio (*14,15*). The purpose of this formulation was to combine the advantages of maximizing the PROS with those of minimizing the DI.

In Release 7 of TRANSYT-7F, an option allows the user to select the PROS/DI ratio as the PI. The model calculates the effective PROS on the arteries and the DI for the entire system after each timing shift. The shift is retained if it increases the PROS/DI ratio.

Unlike simple PROS optimization, this policy considers the PROS and DI at the same time; thus, it eliminates the need for the second optimization step discussed before.

Because the minor movements are accounted for in calculating the DI, splits can be optimized in addition to offsets. This policy tries to maximize progression, subject to maintaining sufficient green times for the minor movements. In addition, the policy attempts to find the set of offsets that clears the existing queue before the platoon's arrival. Nodes not on the designated arteries are explicitly considered in the traditional DI calculation; thus, their offsets and splits are optimized in concert with the arterial progression.

The relative weighting of the $PROS_e$ in the objective function can be varied by

$$PI = (100 \times PROS_e)^{WP}/DI \quad (3)$$

where WP is the relative weight of PROS to the DI.

This allows for fine-tuning the relative importance of the PROS on the arteries versus the DI for all links. Experience with the early version of the model indicated that, in some cases, optimizing splits based on the PROS/DI strategy without weighting tended to discriminate against minor turning movements. Cohen and Liu likewise noted that the earlier optimization strategy resulted in shorter side-street greens (*10*).

To correct this anomaly, it was determined that a WP value of 0.5 would generally reduce the weight of PROS relative to the DI. This increases the weight of minor movements in the optimization and generally results in a better optimization of splits while it maintains good progression on the arteries. It should be noted, however, that this value of WP (0.5) is not likely to be the ideal value for all networks.

Selecting cycle length on the basis of the PROS/DI ratio is also allowed. In this process, the model employs the same procedure as that used by TRANSYT-7F to select the cycle length that produces the best PI.

Directional Weighting

From the traffic engineering point of view, it may be desirable to favor one direction of travel on an artery over another, such as during peak periods. In addition, it may be preferable to give different weights to different arteries. Thus, a weighting strategy is employed by modifying the formulation of Equations 1 and 2 for a specific artery. First, define

$$PROSR_i = \frac{PROS_{i1}}{PROS_{i1} + PROS_{i2}} \quad (4)$$

and

$$WDR_i = \frac{WD_{i1}}{WD_{i1} + WD_{i2}} \tag{5}$$

where

PROSR_i = relative PROS in the "forward" direction (k = 1) on artery i,
PROS$_{ik}$ = actual PROS in direction k on artery i,
WDR_i = relative weighting for the forward direction (k = 1) on artery i, and
WD_{ik} = weighting factors for direction k on artery i.

Now define a desired directional factor for artery i (DDF$_i$):

$$\mathrm{DDF}_i = \frac{\min(\mathrm{PROS}R_i,\ WDR_i)}{\max(\mathrm{PROS}R_i,\ WDR_i)} \tag{6}$$

and the resulting definition of the effective PROS (PROS$_e$) is

$$\mathrm{PROS}_e = \frac{\sum_{i=1}^{A} \mathrm{DDF}_i \sum_{k=1}^{2} WD_{ik} \sum_{j=1}^{N_i} \sum_{t=1}^{C} \mathrm{PROS}_{ikjt}}{\sum_{i=1}^{A} \sum_{k=1}^{2} WD_{ik} \sum_{j=1}^{N_i} \sum_{t=1}^{C} \mathrm{CPROS}_{ikjt}} \tag{7}$$

where A equals the number of arteries.

By weighting the arteries relative to each other, the two directions of travel along each artery, or both, the engineer may be able to influence the resultant design to achieve a desired policy.

MODEL APPLICATIONS

The PROS optimization strategy implemented in TRANSYT-7F was evaluated using two real-world traffic systems: an artery and a two-dimensional network.

Timing plans were designed for the two systems, using the PROS, PROS/DI, and standard DI objective functions in TRANSYT-7F. Only the offsets were optimized initially. Then both offsets and splits were optimized. The DI was consistently defined as excess fuel consumption due to stops and delay.

The resultant designs were compared on the basis of perceived progression and fuel consumption as reflected by the PROS$_e$ and DI values, respectively.

Although macroscopic measures of effectiveness are necessarily reported, the individual runs were examined to ensure that no links were seriously oversaturated such that the results are unfairly biased. In several PASSER II and TRANSYT-7F final solutions, there was some minor oversaturation, but it was more to the disbenefit of the TRANSYT-7F results.

Arterial Application

Cape Coral Parkway, in the city of Cape Coral, Florida, was used as the study artery. This is an east-west artery with seven intersections. The configuration of the artery is presented in Figure 1. The numbers between nodes are the intersection spacings.

The PROS and PROS/DI optimization strategies were compared with the performance optimization strategy as described. The study was performed for the existing phase sequences and the optimal phase sequences selected by PASSER II-90.

For the existing phase sequences, the comparison was repeated using two different initial timing plans. These plans were calculated using the internal initial timing routines of PASSER II and TRANSYT-7F, respectively, to illustrate the point that TRANSYT-7F's optimal solution generally results in a superior plan if its initial timing plan is good. TRANSYT computes the initial splits for pretimed controllers based on equalizing the degrees of saturation on the critical conflicting links. The routine sets all initial offsets to zero. For the optimal phase sequences, the initial timing was that optimized by PASSER II. The TRANSYT-7F internally generated plan was not examined, because it is known that it would result in an inferior design.

The results of the comparative study are summarized in Table 1. As mentioned earlier, the default value used for the relative weight of PROS in the PROS/DI optimization (*WP* in Equation 3) was 0.5. The results used to represent the PROS/DI strategy in the comparative analysis are based on this value unless otherwise stated.

The results of Table 1 indicate that the PROS and PROS/DI solutions were clearly superior to the minimal DI solutions in terms of perceived progression. For the existing phase sequence and the two initial timing plans used (TRANSYT-7F and PASSER II), the PROS/DI optimization strategy increased the PROS$_e$ by 54 and 31 percent, respectively (that is, 39.5 versus 25.6 percent and 39.8 versus 30.4 percent) compared with the DI policy. (All percentages used for comparisons in the test are based on results obtained from optimizing both offsets and splits unless otherwise specified.)

The improvement was less significant when using the PASSER II optimal sequence solution as the initial timing (41.6 versus 40.3 percent, which is only 3 percent). Similar trends were observed when comparing the solutions from the PROS and DI policy with those from the DI policy. For the optimal phase sequence, the hill-climbing process was able to reach a good local optimum, in terms of progression, in the performance optimization. Thus, PROS-based solutions could not improve much over the DI solutions in this case.

In terms of excess fuel consumption, optimization based on PROS or PROS/DI did not result in a serious increase in the DI compared with the performance optimization strategy. In

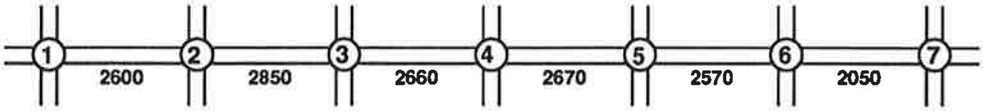

FIGURE 1 Configuration of Cape Coral Parkway.

TABLE 1 Comparison of DI, PROS/DI, and PROS Optimizations for Cape Coral Parkway

Initial Timing/ Sequence	Optimization	Objective Function	$PROS_e$ (%) Right[a]	Left[a]	Total	Bandwidth (sec) Right[a]	Left[a]	Artery DI	Total DI
TRANSYT/ Existing	Offsets only	DI	23.4	24.4	23.9	16	0	94.5	248.6
		PROS	21.4	57.4	39.4	3	73	104.6	252.1
		PROS/DI	31.0	43.2	37.1	12	43	95.0	243.9
	Offsets and Splits	DI	27.0	24.3	25.6	23	0	90.8	246.9
		PROS	24.6	54.3	39.5	5	62	95.1	245.0
		PROS/DI	35.3	43.7	39.5	18	46	92.6	242.7
PASSER II/ Existing	PASSER II	---	23.8	42.2	33.0	24	44	110.4	252.0
	Offsets only	DI	21.2	38.3	29.7	0	22	103.5	243.9
		PROS	28.6	40.3	34.4	23	41	106.8	249.3
		PROS/DI	27.4	40.4	33.9	13	39	104.2	245.5
	Offsets and Splits	DI	20.7	40.2	30.4	6	28	94.9	234.0
		PROS	25.5	45.1	35.3	0	44	97.1	233.1
		PROS/DI	35.5	44.2	39.8	29	47	95.2	240.8
PASSER II/ Optimal	PASSER II	---	31.2	50.3	40.7	36	58	104.6	244.3
	Offsets only	DI	28.7	52.0	40.3	14	54	99.8	237.8
		PROS	30.1	54.8	42.4	27	68	102.7	241.9
		PROS/DI	28.3	54.9	41.6	18	65	100.2	238.4
	Offsets and Splits	DI	28.7	52.0	40.3	14	54	99.8	237.8
		PROS	29.5	55.5	42.5	25	69	103.4	241.9
		PROS/DI	28.3	54.9	41.6	18	65	100.2	238.4

[a] Right and Left refers to the right-bound and left-bound travel on the artery.

fact, in some cases, they produced a lower DI. In these cases, the PROS-based optimization led the hill-climbing process to a better local optimum in terms of the DI. Varying the relative weight of the PROS to DI (as will be shown later) or directional weightings of the PROS may reduce the DI further.

When the PROS or PROS/DI optimization policy was applied to the PASSER II solutions, some improvements in the PROS values were realized. For example, the PROS/DI optimization could increase the $PROS_e$ values by 21 percent (39.8 versus 33.0 percent) and 2 percent (41.6 versus 40.7 percent), respectively, for the existing phase sequence and optimal phase sequence compared with PASSER II solutions.

In terms of systemwide traffic operation as measured by the DI, solutions based on all three optimization strategies in TRANSYT-7F produced improvements over PASSER II solutions in terms of both PROS and DI. It is recognized that PASSER II, by the nature of its objective function, sometimes gives wider through bands.

Generally, when the PROS/DI strategy was used, split optimization resulted in an increase in the PROS and a decrease in the DI. The maximum increase in the $PROS_e$ was 17 percent (39.8 versus 33.9 percent), and the maximum decrease in the DI was 2 percent (240.8 versus 245.5).

When the splits in PROS and DI optimization are adjusted, the process tries to minimize the DI while not reducing the PROS. Considerable reduction in the DI could be realized during this adjustment. Although PROS were not explicitly considered in this process, they might increase due to improvements in the DI on the artery. The maximum improvement achieved in the $PROS_e$ value was 3 percent (35.3 versus 34.4 percent).

As expected, split optimization using the DI objective function generally reduced the DI. It also produced some increases in the PROS values.

For the data set investigated, optimizing the phase sequence using PASSER II improves PROS for all optimization strategies considered, however, its effect on fuel consumption was varied.

Table 1 presents numbers that demonstrate that increasing the PROS did not necessarily result in a decrease in the DI of arterial links (i.e., those most affected by coordination). It is believed that the effect of PROS on the DI of arterial links is a function of many factors, including link lengths, turning movements from cross streets, and degrees of saturation on the artery.

In all cases, the arterial link-only DIs were within a few percentage points for all three optimization strategies (i.e., DI, PROS and DI, and PROS/DI); but in both comparisons with PASSER II solutions, the DIs were lower with PROS/DI or PROS optimization.

Next, an investigation was conducted to assess the benefits of weighting the PROS relative to DI in the PROS/DI formulation. As noted, the PROS/DI policy produced very good progression solutions. Thus, it was decided to use the PROS relative weighting to try to reduce the DI. That implied putting less weight on the PROS relative to the DI.

The results, presented in Table 2, indicate that the DI could be decreased without causing serious reductions in PROS by using a proper weighting. In a few cases, putting less emphasis on PROS by reducing its weight increased the PROS. This suggests a need for more work to assess the stability of this weighting strategy.

Network Application

The network chosen for this study is a 26-intersection network in Flint, Michigan. Its configuration is shown in Figure 2. The PROS-based model implemented in TRANSYT-7F was used in an attempt to improve the perceived progression on two arteries within the system. These two arteries are Dupont and Detroit streets, both of which are north-south arteries with eight intersections.

The results obtained for this network are summarized in Table 3. These results demonstrated significant improvements in the PROS on both arteries when either of the PROS-related functions is used instead of the DI alone.

Compared with the DI minimization policy, PROS/DI maximization increased the $PROS_e$ by 117 percent (46.6 versus 21.4 percent). However, it also increased the DI by 9 percent (193.3 versus 177.6).

The PROS/DI solution was superior to the PROS and DI solution in terms of both PROS and DI. The PROS/DI optimization produced a 46 percent (46.6 versus 31.8 percent) increase in the $PROS_e$ but a minimal 0.8 percent (that is, 193.3

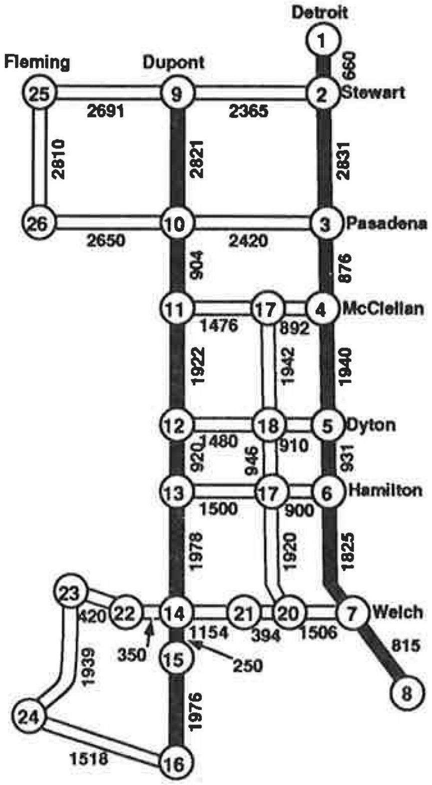

FIGURE 2 Flint network configuration (distances in feet).

TABLE 2 Effect of Changing Relative Weight of PROS to DI

Phase Sequence	Initial Timing	PROS Weighting Factor	$PROS_e$ (%) Right[a]	Left[a]	Total	Bandwidth (sec) Right[a]	Left[a]	Artery DI	Total DI
Existing	TRANSYT	1.00	36.4	46.6	41.5[b]	29	50	88.3	248.3
		0.60	30.0	51.0	40.5	20[b]	60	94.5	246.5
		0.50	35.3	43.7	39.5	18	46	92.7	242.7
		0.40	36.7	43.2	39.9	28	46	93.7	244.4
		0.30	36.1	42.4	39.2	27	38	93.5	249.4
		0.20	28.4	43.7	36.1	13	46	94.0	241.3[b]
		0.10	19.7	43.4	31.6	6	33	90.6	246.6
Existing	PASSER II	1.00	30.9	53.3	42.1[b]	19[b]	59	91.4	246.5
		0.60	36.1	43.6	39.9	31[b]	47	95.8	241.5
		0.50	35.5	44.2	39.9	29	47	95.2	240.8
		0.40	33.0	43.8	38.4	13	37	91.4	238.2
		0.30	29.6	48.2	38.9	17	49	91.4	237.6
		0.20	30.8	45.4	38.1	27	51	96.6	235.0
		0.10	31.9	42.3	37.1	28	45	95.7	234.2[b]
Optimal	PASSER II	1.00	35.6	53.3	44.5[b]	26	54	93.1	256.9
		0.60	29.6	53.7	41.6	20	62	100.8	238.4
		0.50	28.3	54.9	41.6	18[b]	65	100.2	238.4
		0.40	33.6	48.0	40.8	22	56	98.8	237.5
		0.30	32.6	47.9	40.3	18	58	97.6	236.3[b]
		0.20	29.4	53.3	41.4	17	58	99.8	237.5
		0.10	28.9	53.7	41.3	16	58	100.4	238.2

[a] Right and Left refers to the right-bound and left-bound travel along the artery.
[b] Indicates the "best" solution for each measure. In the case of bandwidth, the "best" applies to both directions.

TABLE 3 Comparison of DI, PROS/DI, and PROS Optimizations for Flint Network

Optimization	Objective Function	PROS Weight (WP)	Artery Number	PROS$_e$ (%)			Bandwidth (sec)		Artery DI	Network DI
				Right[a]	Left[a]	Total	Right[a]	Left[a]		
Offsets Only	DI	__[b]	1	20.6	19.4	21.0	0	0	36.4	
			2	14.0	30.0		0	11	35.7	200.3
	PROS	__[b]	1	47.7	14.8	31.9	27	0	40.9	
			2	26.8	38.2		12	19	34.7	207.5
	PROS/DI	0.5	1	24.0	29.4	29.3	1	9	38.6	
			2	25.1	38.6		11	20	34.4	198.9
Offsets and Splits	DI	__[b]	1	13.9	17.1	21.4	0	0	33.5	177.6
			2	21.1	33.3		0	9	27.9	
	PROS	__[b]	1	31.0	29.0	31.8	14	1	31.1	194.9
			2	29.9	37.2		11	17	26.3	
	PROS/DI	0.5	1	38.7	45.2	46.6	10	19	30.4	193.3
			2	39.8	62.7		18	36	32.0	
	PROS/DI	0.2	1	15.4	30.7	33.1	0	11	32.2	181.2
			2	30.5	55.9		7	30	32.6	

[a] Right and Left refers to the right-bound and left-bound travel on the artery

[b] "__" Means that the WP is not applicable in this case.

versus 194.9) decrease in the DI relative to the PROS and DI optimization.

By using the proper directional and arterial weightings or relative PROS–to–DI weighting, the resultant designs might be further improved. For example, using a *WP* of 0.2 in the PROS/DI optimization produced a good design from both the PROS and DI perspectives. This strategy increased the PROS$_e$ by 55 percent (33.1 versus 21.4 percent) with only a small increase in the DI (181.2 versus 177.6, which is 2 percent) compared with the performance optimization solution.

CONCLUSIONS AND RECOMMENDATIONS

From the results presented in this study, it can be concluded that the PROS concept has been successfully implemented in TRANSYT-7F and that it is a practicable design tool for networks. The PROS and PROS/DI optimization strategies significantly improve progression over the normal performance optimization in TRANSYT-7F. These improvements are realized for single arteries as well as multiarterial networks.

Designs based on either of the PROS-related objective functions for individual arteries compare favorably with the solutions obtained by a bandwidth optimization program. The new version of TRANSYT-7F can now deal with multiple arteries within a network.

The two PROS-related strategies combine the advantages of maximizing progression with that of minimizing the DI. It appears that these functions can be used instead of the traditional performance optimization strategy of TRANSYT when the objective is to optimize both progression and fuel consumption.

The use of proper relative PROS–to–DI weighting, directional weightings, and arterial weightings appears to have merit. More work is required to improve these strategies.

The macroscopic simulation model in TRANSYT-7F was used to assess the effectiveness of different optimization strategies in reducing fuel consumption. Although the TRANSYT-7F simulation model is realistic and widely accepted, there is a need to validate the PROS-based model by field testing, or at least by using a microscopic simulation model such as TRAF-NETSIM (*18*). Further research is suggested to ensure that all aspects of the PROS-based optimization are stable, particularly with respect to weighting factors.

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