CALIBRATION OF TRANSYT PLATOON DISPERSION ALGORITHM FOR CONDITIONS ALONG MAJOR ARTERIALS IN THE CITIES OF DAMMAM AND AL-KHOBAR, SAUDI ARABIA

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الخلاصـة :

إن درجة المصداقية والفعالية لبرنامج "TRANSYT" تعتمد اعتماداً رئيساً على القدرة الخوارزمية المستخدمة في البرنامج، والتي تقوم بتشتيت المركبات ومن ثم التنبؤ بنمط سير الحركة المرورية من إشارة ضوئية إلى أخرى، وهذه الخوارزمية تعتمد على فكرة أن مجموعة من المركبات التي تبدأ متلاصقة في بداية السير تتشتت بشكل متواصل أثناء تنقلها من تقاطع إلى آخر على الطريق. إنَّ كمية التشتت التي تتنبأ بها هذه الخوارزمية تعتمد على مدى ملائمة ثابت عددي يدعى الثابت "PDF".

تهدف هذه الدراسة إلى إيجاد قيمة ذلك الثابت العددي "PDF" والذي يُحاكي حالة الحركة المرورية في منطقة الدراسة على أفضل وجه. لقد أُجريت الدراسة على امتداد طريقين من الطرق الشريانية الرئيسية المتواجدة في منطقة تختلط فيها النشاطات التجارية والسكانية، ويتكون كل طريق من أربع تقاطعات رباعية الشعب ومزودة بإشارات ضوئية من أربع مراحل مسبقة التوقيت، وقد استنتج من هذه الدراسة أن أفضل قيمة للثابت "PDF" في منطقة الدراسة هو (٢٨) للطرق القليلة الاحتكاك و(٤٠) للطرق المتوسطة الاحتكاك، هذا بينما يُوصي كُتَيِّب برنامج "TRANSYT" باستخدام (٢٥) للطرق القليلة الاحتكاك و(٣٥) للطرق المتوسطة الاحتكاك (الاحتكاك يشير إلى عدة عوامل من أهمها عدد السيارات المتوقفة على جانبي الطريق وكمية حركة المشاة) وقد تبيَّن أن الاختلاف في قياسات الأداء الناتجة عن استخدام نتائج هذه الدراسة عوضاًعن توصيات كتيب برنامج "TRANSYT" هي اختلافات بسيطة وليست جوهرية.

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ABSTRACT

The reliability and effectiveness of the TRANSYT model depend primarily on the ability of its platoon dispersion algorithm to accurately predict the flow pattern from one signal to another. The algorithm is based on the theory that a platoon of vehicles starting from an upstream intersection will continuously disperse as it travels downstream along the link. The amount of dispersion in the traffic flow pattern, as predicted by this algorithm, depends on the proper value of an empirical constant in the algorithm referred to as the "Platoon Dispersion Factor" (PDF). The objective of this study was to determine the value of PDF which best simulates the traffic conditions in the study area. The study was conducted along two major arterials in areas of mixed residential and commercial activities. Each arterial consisted of four signalized intersections with four approaches to each of them. The signals at these intersections were pre-timed with four protected phases. It was concluded that the average best fit (calibrated) PDF values in the study area were 28 and 40 for low and moderate friction links, respectively. On the other hand, the TRANSYT-7F manual suggests a value of 25 for low friction links and 35 for moderate friction links. Nevertheless, the change in performance measures resulting from using the calibrated PDF value over the suggested ones was small and seems to be within the accuracy of the TRANSYT-7F model.

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1. INTRODUCTION

The TRANSYT model [1] is composed of two main sections: a traffic model and an optimization procedure. The traffic model is a macroscopic, deterministic simulation model. The term "macroscopic" refers to the fact that the model considers groups of vehicles (hereafter called "platoons") rather than individual vehicles. The simulation process is based primarily on simulating the dispersion of platoons as they progress along network links. This is done by using a platoon dispersion algorithm developed by Robertson [1]. The algorithm describes (collectively) the desire of individual drivers to maintain comfortable time headway as they progress along network links. Based primarily on Webster's methodology [2], the traffic model calculates delay and stops for each network link. Following that, the weighted sum of the delay and the number of stops suffered by all vehicles in the network are obtained and called the "performance index" or "PI" of the network.

The optimization procedure is an iterative, gradient search (hill-climbing) technique that optimizes signal phase lengths (*i.e.* splits) and offsets of a signalized network. This is done by changing splits and offsets systematically in search of those which produce minimum PI.

The reliability and effectiveness of the TRANSYT model depends primarily on the ability of its platoon dispersion algorithm to accurately predict the flow pattern from one signal to another. The platoon dispersion algorithm used in TRANSYT is considered to be one of the most realistic algorithms used in macroscopic traffic simulation models [3]. It is based on the theory that a platoon of vehicles starting from an upstream intersection will continuously disperse as it travels downstream along the link. Robertson [1] developed the following recurrence relationship to simulate this phenomenon:

$$Q^1(i+\beta t) = F * Q(i) + \{(1-F) * Q^1(i+\beta t-1)\}$$

$Q^1(i+\beta t)$ = number of predicted arrivals in interval $i+\beta t$ at a point downstream of a signalized intersection;

$Q(i)$ = number of departures in interval i from the signalized intersection;

β = empirical travel time factor expressed as ratio between average travel time of leading vehicle in platoon and average travel time of entire platoon;

t = average travel time from the signalized intersection to the point at which the platoon is being calculated;

F = empirical smoothing factor which controls rate at which platoon disperses, expressed as $F = 1/(1+\alpha\beta t)$;

α = empirical dispersion factor.

It is clear that the amount of dispersion in the traffic flow pattern, as predicted by the above recurrence equation, depends on the values of α and β. The proper values of α and β are a function of the traffic conditions and geometric features of the network under consideration. For similar traffic conditions and geometric features, different values of α and β are reported in different countries [1, 3–8]. This might be explained by the fact that driver performance characteristics and habits differ from one society to another. In all versions of the TRANSYT model the parameter β takes a default value of 0.8 which cannot be changed by the user. Therefore, a number of studies calibrated the model by determining the best value of α while β is set at its default value [9–12]. Some researchers indicated that such a calibration scheme produces satisfactory, but not necessarily the best, results [3, 10]. Nevertheless, this is the only scheme that can be used for calibrating and utilizing the TRANSYT model in any local conditions.

2. OBJECTIVES OF THE STUDY

1. To determine the value of α (which is referred to as PDF in the model) which best simulates the traffic conditions of Al-Khobar and Dammam cities.
2. To determine if such PDF values provide better results than those recommended by the TRANSYT-7F manual.

3. STUDY SITES

The TRANSYT model cannot simulate traffic in a network possessing different cycle lengths. Thus, to be capable of simulating the traffic in a network (and consequently to calibrate the model), the entire network must have one cycle length or a multiple of this common cycle. Only one arterial in Dammam and one arterial in Al-Khobar satisfied this criterion. The two arterials were very similar and their geometric features were ideal (*i.e.* 12-foot lanes, no horizontal or vertical alignment, *etc.*). Each arterial consisted of four signalized intersections with four approaches to each, three lanes in each direction, and they were both oriented in the North–South direction in areas of mixed residential and commercial activities. The signals at these intersections were pre-timed with four protected phases and a common cycle length of 120 seconds.

4. DATA COLLECTION

For calibrating the model, the arrival flow pattern profiles were obtained for six links (three for northbound traffic and three for southbound traffic) connecting the four intersections in each arterial. For each link, the observed arrival profile (histogram) was constructed by counting the vehicles arriving at a point upstream of the investigated intersection at a distance large enough to insure that the arriving flow pattern was not disturbed or influenced by the vehicles queuing at the downstream intersection. Given that the cycle length in the study area was 120 seconds, the cycle length was divided into 24 intervals, each of which was five seconds long. The number of vehicles arriving in each interval was counted separately. This was done over 30 consecutive cycles, which represented a one-hour study period.

4.1. Estimation of PDF Values in the Study Area

By comparing the traffic and geometric features for each link with the characteristics of different levels of roadway friction as given in the TRANSYT-7F* manual [13], the roadway friction on each link was classified as being either low or moderate. The manual recommends a platoon dispersion factor (PDF) of 25 for low friction and 35 for moderate friction. Thus, the recommended PDF values for each link were determined from the manual.

To divide these two categories of links (*i.e.* links with moderate friction and links with low friction) evenly between the calibration and validation studies, the links serving northbound traffic in Al-Khobar and Dammam were used in the calibration study, and southbound links were used in the validation study (see Tables 1 and 2).

5. CALIBRATION OF THE MODEL

Calibration consists of determining the value of the platoon dispersion factor (referred to as α in the Robertson dispersion algorithm and as PDF in the TRANSYT-7F model) which, when used in the TRANSYT-7F model, achieves the best agreement between the observed traffic flow patterns and those simulated by the model.

Starting with the first link serving northbound traffic in Al-Khobar (Link 9401), the PDF value which produces the best agreement between the observed and simulated flow patterns was determined by conducting several simulation runs for the entire arterial. In each simulation run, a different value of PDF was used for the first link. For all other links in the arterial, the recommended PDF values were used. In each simulation run, a flow profile was requested for the exact point on the first link where the arrival flow data was collected. The sum of absolute difference criterion, which is the minimization of the absolute value of the total differences between the number of vehicles simulated and observed in each interval of the cycle over the study period, was used to compare the

* The Americanized version of the TRANSYT model which was available to the author.

simulated flow profile plots with the observed flow pattern. Thus, the best PDF value which satisfies the absolute difference criterion was determined for the first link. Figure 1 shows how the sum of absolute differences changes with different values of PDF for the first link serving the northbound traffic in Al-Khobar. With the aid of such a graph, the PDF value that satisfies the sum of absolute differences criterion can be identified, which in this case is 31. Figure 2 shows the observed traffic flow pattern superimposed over the simulated one using the best fit PDF value of 31. Using the best fit value of PDF for the first link and the recommended PDF values for all other links, the same procedure was repeated for the second and third links serving northbound traffic in the city of Al-Khobar. This methodology was then repeated for the links serving northbound traffic in Dammam.

6. CALIBRATION RESULTS

Table 1 summarizes the results of the calibration effort. As can be seen from this table, there is a clear tendency for the best PDF value to be greater than the one suggested by the TRANSYT-7F manual, for both low and moderate friction categories. More specifically, the best PDF values ranged between 26 and 31 for low friction links and it was exactly 40 for the links with moderate friction. The average of the best fit PDF values may be considered as the calibrated PDF values for the study area. Hence, the calibrated PDF values are 28 and 40 for low and moderate friction links, respectively.

Table 1. Calibration Results.

*% Error in Volume	†Sum of Absolute Difference	‡Best PDF Value	§Suggested PDF Value	§Roadway Characteristics	City and Direction	Link # (Node-Node)
13.1	139	31	25	Low friction	Al-Khobar N.B.	9401 (24-23)
12.1	125	27	25	Low friction	Al-Khobar N.B.	9201 (23-22)
13.4	146	40	35	Moderate friction	Al-Khobar N.B.	9001 (22-21)
13.4	115	26	25	Low friction	Dammam N.B.	9101 (12-6)
18.1	118	29	25	Low friction	Dammam N.B.	9201 (6-7)
14.4	117	40	35	Moderate friction	Dammam N.B.	9301 (7-1)

* (Sum of absolute difference/observed volume) × 100.
† Sum of absolute difference between observed flow profile and the one simulated by the best PDF value (vehicle/hr).
‡ The PDF that minimizes the absolute difference between observed and simulated flow profiles.
§ From TRANSYT-7F manual recommendations.

Table 2. Validation Results.

Calibrated Value found in this study			TRANSYT-7F Recommendation			Roadway Characteristics	City and Direction	Link Number
% Error*	Sum Abs.** Diff.	PFD Value	% Error*	Sum Abs.** Diff.	PDF Value			
13.6	137	28	15.0	151	25	Low friction	Al-Khobar S.B.	9103
14.3	147	28	14.6	150	25	Low friction	Al-Khobar S.B.	9303
16.0	170	28	17.3	184	25	Low friction	Al-Khobar S.B.	9503
21.3	132	40	22.4	139	35	Moderate friction	Dammam S.B.	9403
22.3	117	40	24.0	126	35	Moderate friction	Dammam S.B.	9503
15.7	115	28	15.0	110	25	Low friction	Dammam S.B.	9603

* (Sum of absolute difference/volume along the link) × 100.
** Sum of absolute difference between observed and simulated flow profiles (vehicle/hr).

7. VALIDATION OF THE MODEL

Using the calibrated average PDF values found in the previous section (28 and 40), the flow along each validation link was simulated. The resulting flow profiles were then compared to those observed in the field.

The flow along each of the above links was also simulated using the PDF values suggested by the TRANSYT-7F manual and the resulting flow profiles were compared to those observed in the field. This was done to compare the calibrated PDF values with those suggested by the manual. The results of this validation effort are summarized in Table 2.

Considering the "sum of absolute differences" as a comparison criterion between the results obtained using the calibrated and recommended PDF values, the following conclusions were reached:

1. With the exception of the last link in Dammam (# 9603), the calibrated PDF values provided superior results.
2. The differences are not large. The improvement in the comparison criterion is less than 2% of the observed volume along any link.
3. To understand the behavior of link 9603, it was calibrated by following the procedure of the calibration process and consequently its best fit PDF value was found to be 25. The fact that the best fit PDF value for this link is equal to the recommended value, where the value used in the validation was 28, explains why link

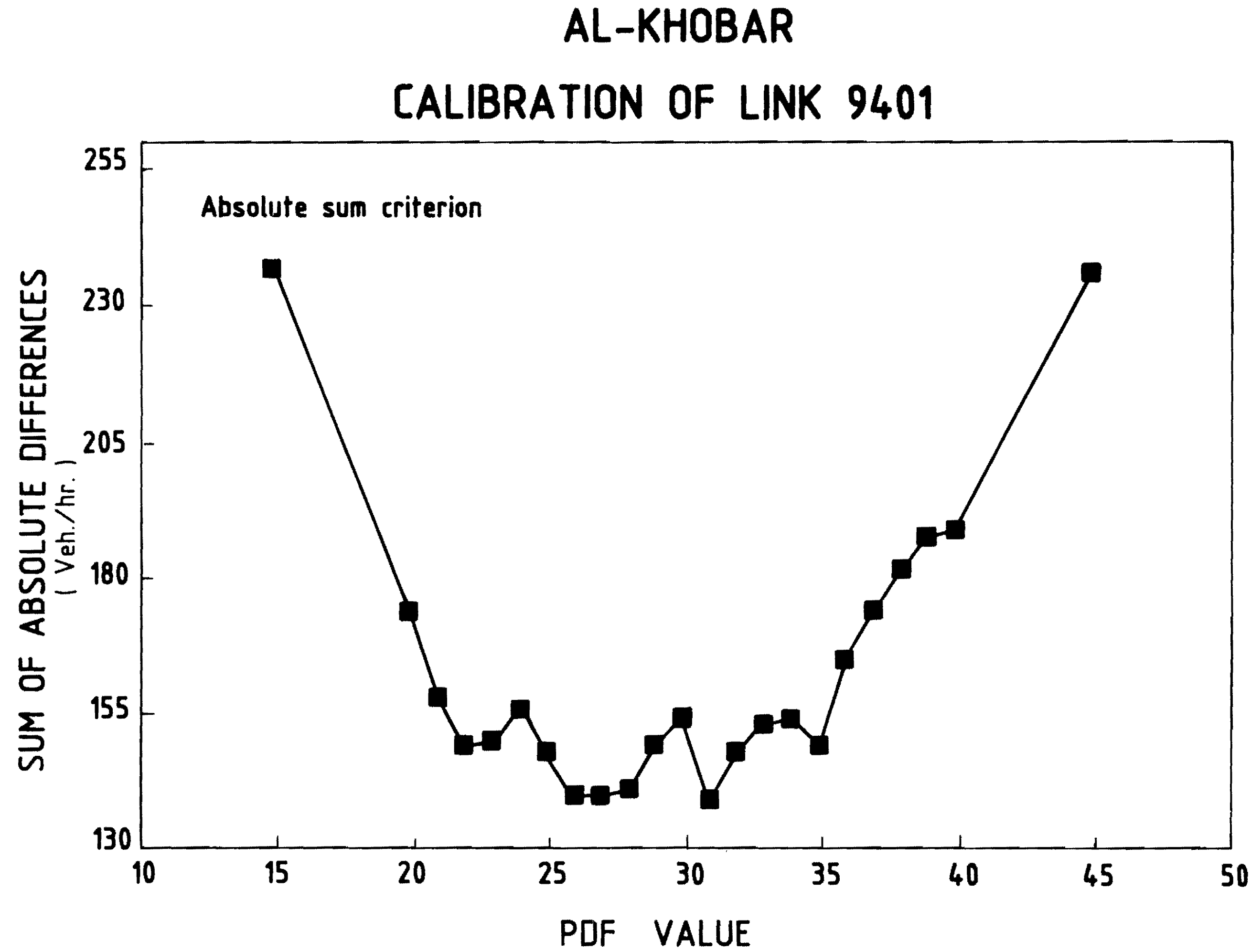

Figure 1. Calibration of Link 9401.

9603 is an exceptional case. Nevertheless, the difference (in terms of the comparison criterion) between the results obtained using the calibrated and recommended PDF values for this link is small.

Identical average PDF values were obtained when the links which were originally used in the validation process were calibrated. The same was also true when all of the twelve links were calibrated. These facts enhance the confidence of the resulting average PDF values of the study area.

Consequently, it was concluded that, on average, the best (*i.e.* calibrated) PDF values in the study area are 28 and 40 for low and moderate friction, respectively. Furthermore, these calibrated PDF values provided some improvement over the PDF values suggested by the TRANSYT-7F manual.

8. SENSITIVITY ANALYSIS

In terms of reducing the discrepancies between simulated and observed traffic flow patterns, the calibrated PDF values provided slightly better results than those recommended by the manual. However, this difference is only important if the consequences of developing and implementing an optimal signal timing plan differ depending on which set of PDF values are used. More specifically, it is more important to determine if the performance measures (*i.e.* delay, stops, *etc.*) would be improved by using the calibrated PDF values over the recommended ones in optimizing signals in the study area. It is also important to determine if such improvement is large enough to justify the considerable amount of effort spent in developing the calibrated PDF values.

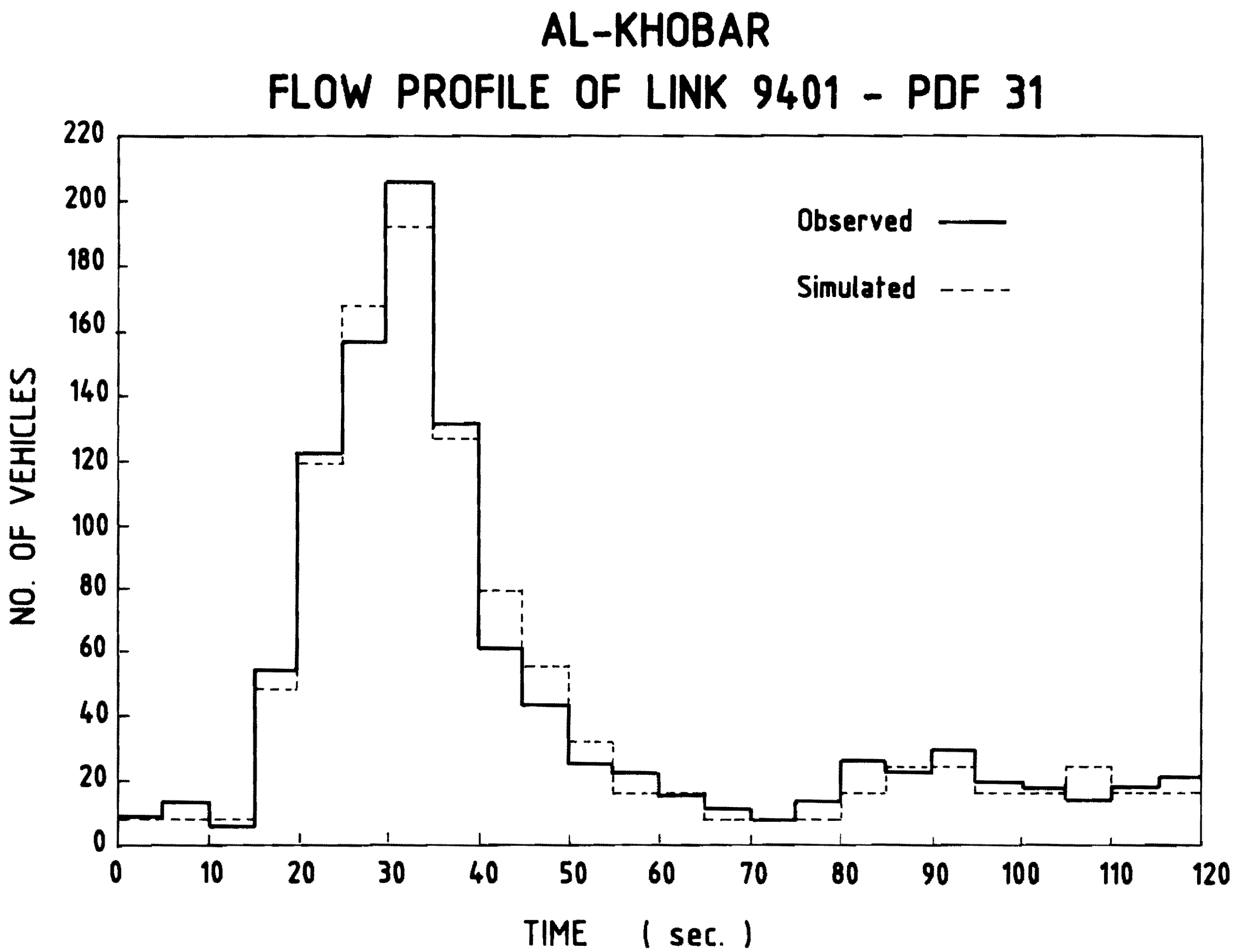

Figure 2. Observed and Simulated Flow Profiles of Link 9401.

To make these determinations, the performance measures resulting from using different sets of PDF values in optimizing the studied arterials have to be compared and evaluated. To do this, the following specific procedure was followed throughout the sensitivity analysis:

1. To make the analysis easier, the two arterials were connected to form one hypothetical arterial consisting of eight signalized intersections, which will be referred to from now on as the arterial.
2. The calibrated PDF values (*i.e.* 28 and 40 for low and moderate friction, respectively) were used in developing an optimal signal timing plan for the arterial.
3. The optimal signal timing plan (signal splits and offsets) was simulated using the same calibrated PDF values. Thus, the performance measures (*i.e.* delay, stops, PI, *etc.*) resulting from implementing the optimal signal plan were determined. For convenience, these performance measures will be referred to as $PM_{28\&40}$.
4. Using the recommended PDF values (*i.e.* 25 and 35 for low and moderate friction, respectively), another optimal signal timing plan was developed for the same arterial. This plan will represent the result that would be obtained by not using, or knowing, the appropriate PDF values of the study area.
5. To evaluate the non-optimal plan (part 4), the arterial was simulated using the appropriate (*i.e.* calibrated) PDF values. Consequently, the above plan was developed using the recommended PDF values and simulated using the calibrated ones. The performance measures resulting from simulating this plan are referred to as $PM_{25\&35}$. These measures ($PM_{25\&35}$) resemble the actual behavior of traffic if the plan found in part 4 is adopted.
6. Comparing the performance measures obtained in part five ($PM_{25\&35}$) to those found in part three ($PM_{28\&40}$) will indicate how much improvement can be achieved by using the calibrated (*i.e.* the appropriate) PDF values. More specifically, the following criterion was used to determine the level of improvement:

$$\left[\{(PM_{25\&35} - PM_{28\&40})/PM_{28\&40}\} * 100\right].$$

Positive values of the above criterion mean that the calibrated PDF values provided better results (positive improvement), and vice versa.

Using the above procedure and criterion, Table 3 shows the percentage change in performance measures resulting from using the calibrated PDF values (rather than those suggested by the manual). It is clear from Table 3 that the change in any performance measure never exceeded 1.03%.

To determine whether such a value has practical significance, a simple experiment was conducted. In this experiment, the arterial was optimized twice. The only difference between the two optimization runs is the intersection (*i.e.* node) order used by the model in the optimization process. In the first run, the nodes were ordered as they were faced by the northbound traffic. Thus, the model first optimized the most upstream (external) node in the northbound direction. Then, moving in the same northbound direction, the second node was optimized, and so on. In the second run, the nodes were ordered as they were faced by southbound traffic. Consequently, the node order of each run is a mirror image of the other. Table 4 shows the results of reversing the node order in optimizing the arterial. It can be seen from Table 4 that the minimum change in performance measures is 1.09%. Theoretically, using either node order is equally correct. Recalling that 1.03% is the maximum change in any performance measure resulting from using the calibrated PDF values (Table 3), it appears that the benefits that can be obtained by using the calibrated PDF values are practically insignificant when compared to the minimum of 1.09% change that can result by just reversing the node order in the optimization process.

Furthermore, Table 3 shows that all performance measures, except "Total Delay," suffered from negative changes which are contrary to common sense. A negative change means that if two optimal signal timing plans were developed for a given arterial, the first using the wrong PDF values and the second using the correct ones, the traffic performance resulting from implementing the first optimal plan would be better than that resulting from implementing the second one.

Table 3. Improvement in Performance Measures.

PDF value used in obtaining the optimal signal plan	PDF value used in simulating the optimal signal plan	Cycle length (sec)	*Performance measures obtained from simulation runs				
			Total Delay (v/hr)	Avg. Delay (sec/v)	Uniform stops (v/hr)	Fuel cons. (li)	Performance Index (PI)
25 & 35	28 & 40	80	151.77	13.2	15156	2049.69	299.12
28 & 40	28 & 40	85	151.45	13.1	15314	2052.67	300.33
Percentage Improvement in Performance Measures			†0.21	0.76	−1.03	−0.15	−0.40

* By simulating the optimal plan with calibrated PDF values.
† 100 × {(1st row–2nd row)/2nd row}.

Table 4. Results of Reversing the Node Order in Optimizing the Arterial.

PDF	Node order in optimization	Direction	Total Delay (v/hr)	Avg. Delay (sec/v)	Uniform stops (v/hr)	Fuel cons. (li)	Performance Index (PI)
25 & 35	*12, 6, 7, 1, 24, 23, 22, 21	†North bound	145.04	12.6	14675	2019.28	287.71
25 & 35	21, 22, 23, 24, 1, 7, 6, 12	*South bound	150.26	13.0	15053	2041.53	296.61
% Difference between performance measures of the first and second row			‡+3.47	+3.08	+2.51	+1.09	+3.00

* The direction used in Table 3.
† The reversed direction.
‡ (Southbound – Northbound value) / Southbound value.

From all of the above, it appears that the changes in performance measures are within the accuracy of the model, and there is no evidence to consider such changes as significant "improvements" resulting from using the calibrated PDF values over the suggested ones.

9. SUMMARY & CONCLUSIONS

The general conclusions of the study can be summarized as follows:

1. The average best fit (calibrated) PDF values were 28 and 40 for the low and moderate friction links, respectively. On the other hand, the TRANSYT-7F manual suggests a value of 25 for low friction links and 35 for moderate friction links.

2. The average best fit 'PDF' values provided some improvement over those suggested by the TRANSYT-7F manual in terms of reducing the discrepancies between the observed and simulated flow profiles.

3. The change in performance measures resulting from using the calibrated PDF value over the suggested ones is small and seems to be within the accuracy of the model.

In summary, this study indicates that there is little value in developing a calibrated set of 'PDF' values for use in the cities of Dammam and Al-Khobar. Since this study was conducted on a small sample of the road network in these two cities, this conclusion should not be taken for granted in situations different from those studied.

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