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NOAA Technical Memorandum NWS T&EL-11

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Discussion of Sensor Equivalent Visibility

Staff,
Observation Techniques Development
and Test Branch

Systems Development Office
Test and Evaluation Laboratory
Sterling, Va.

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WBTM T&EL 8 Final Report - The AMOS V Observer Aid Test, Part II. Elbert W. Atkins and Walter E. Hoehne, March 1969. (PB-183 810)

WBTM T&EL 9 Analysis of Visibility Observation Methods. Frederick C. Hochreiter, October 1969. (PB-188 327)

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NWS T&EL 10 Analysis of Cloud Sensors: A Manual Height Measurement System. Staff, Observation Techniques Development and Test Branch, March 1971. (COM-71-00549)

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Staff, Observation Techniques Development and Test Branch

ABSTRACT

One goal of this report is to collate and update background information on attempts to translate visibility sensor measurements to an equivalent of human visibility. The operation of the current standard visibility sensor (NBS-type transmissometer) is described. The human observation of visibility and the manner in which transmissometer measurements are translated to runway visual range and runway visibility are discussed, along with the limitations of such conversions.

The other goal of this report is to present results of an experiment in which human observations of visibility are statistically compared with several equivalents derived from transmissometer measurements. Of those compared, none are completely representative of the human observations in the data examined. This results from many factors which influence, in different ways, human observations and processed data obtained from objective sensors.

1.0 INTRODUCTION

In his classic work on the observation of visibility, Middleton (1952, p. 3) wrote:

> "The problem...is to establish usable theoretical relationships between light, eye, target, and atmosphere that will permit the calculation of the visual range at any time; and to provide means of measuring the necessary parameters quickly and accurately enough. The problem is not yet completely solved, being a very complex one."

Efforts to unravel the problem, as expressed by Middleton, have continued through the years. Although still persistently complex, and not yet completely resolved, applied research and sensor development have at least reduced the problem. Evidence of this is the increasing acceptance of objective visibility sensors, particularly in aviation and marine applications. But despite the adoption of visibility sensors for specialized purposes, the translation of objective measurements to human terms and the development of adequate understanding by the user of these measurements, remain knotty problems.

The group of instruments that are characterized as "visibility sensors" do not, in fact, measure visibility. Instead, they measure properties more directly related to the physical characteristics of the atmosphere than to how far a human can see a target. As the need for objective observations of visibility has increased, so have the number of available sensors and the principles upon which their operation is based. A recent review for example, lists 18 modern visibility measuring systems (ref. 2). Each measures a physical property of the atmosphere that, by accepted convention, is converted to some equivalent of human visibility. Some differences exist in the world meteorological community regarding details of the conversion, but the theoretical principles are generally the same.

This report has two primary purposes:

(1) To collate and update background information on attempts to translate visibility sensor measurements to an equivalent of human visibility;

(2) To present results of an experiment in which human observations of visibility are statistically compared with equivalents derived from processed visibility sensor measurements.

Discussion will be limited to the visibility sensor that, currently at least, is in the greatest use in this country: the NBS-type transmissometer.

2.0 THE SENSOR

In the United States there is but one visibility sensor system used for aviation weather reporting by the NWS and FAA; the NBS-type transmissometer (fig. 1) coupled with a day/night switch. The transmissometer was developed in the early 1940's (ref. 3) and except for some minor modifications, has remained relatively unchanged through the years. The system includes a light projector, a receiver, and a readout device. The distance between the projector and receiver (the baseline) is usually 250 or 500 feet. The sensor components are generally mounted on towers 15 feet above ground level.

The projector is a bright, stable light source which is directed along a baseline to the receiver in a plane parallel to the ground. The light, in passing through the sampling path, is diminished because of beam divergence due to distance and is attenuated by atmospheric elements such as fog, haze, smoke, dust, and precipitation. The residual light strikes a sensitive photoelectric receiver which converts the energy to an electrical pulse train. The pulse rate is proportional to the illuminance at the receiver. Four thousand pulses per minute are equivalent to the illuminance received when absolutely pure air exists along the path sampled (defined as 100% transmittance).

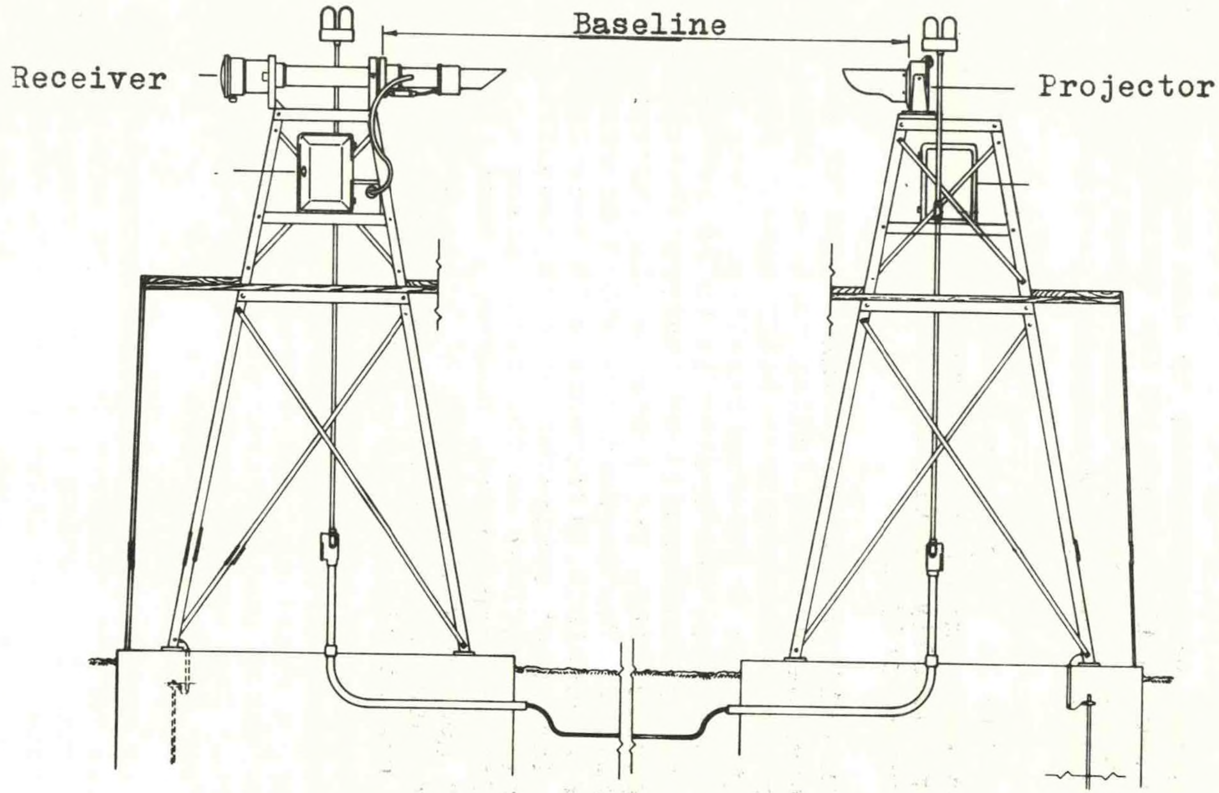

Figure 1.--The Transmissometer System

Under identical transmittance conditions, a light can generally be seen farther in the dark than can the contrast of an unlighted target against its background during daylight. Hence, information concerning ambient illumination is needed to convert the transmissometer output (which is solely an indication of atmospheric transmittance) to a practical value of visual range. An elementary illuminometer, the day/night switch, supplies a substitute for this information.

The transmissometer readout device is driven by the receiver output. Depending on the nature of the desired information, the readout device assumes several forms. Among them are special meter faces, analog charts, and computer generated digital values.

The transmissometer is subjectively calibrated; that is, the system is adjusted to match an observer's estimate of visibility. Calibrations are usually restricted to periods of relatively high and uniform visibility.

Small errors in calibrating the transmissometer can lead to large differences between its indications and prevailing visibility during high transmittance conditions. For example, consider a system with a 500-foot baseline. When prevailing visibility is 34 miles, the system is to be set at 99.0% transmittance. If the system should be incorrectly set only 1% low, a reasonable possibility, the system would indicate visibility as low as 12 miles. Two percent low would generate a read-out of 9 miles, or a possible difference with prevailing visibility of 25 miles. Incorrect estimates of high prevailing visibility could have a similar effect on the calibration of the transmissometer. Calibration errors, however, tend to diminish as the visibility goes down. Because of this, transmissometer indications are used quantitatively in current practice when visibility is relatively low, usually below 2 miles.

3.0 THE SENSORY OBSERVATION

The term "sensory observation" is not frequently used by the meteorological community. It is defined by the World Meteorological Organization (WMO) as "an observation taken by an observer without the use of a measuring instrument but estimated by experience only" (ref. 4). Although in U.S. observing practices the observer may use a visibility sensor as an aid under very limited circumstances, we will use "sensory observation" to refer to any subjective estimate of visibility made by the human surface-weather observer.

FMH #1 (ref. 5) describes three types of visibility observations: RVR, RVV, and prevailing visibility. The first two are highly specialized and have an accepted method by which they can be derived from transmissometer measurements. The third type, prevailing visibility, has the broadest application, but has not yet been successfully replicated by objective visibility sensors.

In the United States, RVR and RVV observations are rarely sensory observations by FAA and NWS observers. Instead, transmissometer measurements are translated to RVR and RVV by means of computer or meter readout. The mathematical relationships used for this purpose are discussed later in this report. The conventions used to derive RVV are identical to those used by human observers to calibrate the transmissometer.

FMH #1 specifies the manner in which sensory observations of visibility will be taken and reported. It defines prevailing visibility as, "The greatest horizontal visibility prevailing throughout at least half of the horizon circle which need not necessarily be continuous. Prevailing visibility is determined as required, at either the usual site(s) of observation or from the control tower level."

The observers are encouraged to take observations from as many locations as are necessary to view all visibility targets. Where practical, the sensory observations should be with reference to the horizontal plane 6 feet above the ground. Exceptions are made for observations taken from the roof of a building or at the control tower. The environment in which the observer works (height and location of obstructions such as buildings and hills, and the location of the observer's console) does much to control the observing site. Naturally, these elements vary widely between weather observatories.

Several important assumptions are made concerning the observation. They are that the observers have average visual acuity; they have one or more stationary observation sites; and the visibility targets are stationary markers viewed against the horizon sky by day, or are stationary low to moderate intensity unfocused lights at night.

Visibility targets are rarely, if ever, installed at sites specifically for the purpose of making sensory observations. Instead, the observer must use those markers available to him, even when they are less than ideal. Preference for daylight visibility targets is given to dark or nearly dark objects outlined against the horizon sky. At night, the ideal targets are unfocused lights of moderate intensity at known distances. Focused lights may be used as guides but not as definite markers.

Instructions are given to allow the observer a means of estimating visibility when the visual range is greater or less than the distance to the reference marker. WMO instructions state that the reference marker must be seen and recognized to qualify as meteorological visibility. Instructions in FMH #1 are not clear as to whether recognition or detection is the condition sought.

There are several factors which may reduce the accuracy of a sensory observation of visibility taken by even the most dedicated observer. These elements create variations in accuracy between observers at the same weather station, between observers at different weather stations, and between observations made by a single observer at different times on his work shift. Among them are:

a. Insufficient dark or light adaptation of the observer.

b. Below standard or nonexistent visibility markers.

c. Nonuniform distribution of visibility markers.

d. Rapidly varying and nonhomogeneous local weather situations which affect visibility.

e. Variations in observer skills.

f. Psychological and physiological differences in observers.

4.0 SENSOR EQUIVALENT VISIBILITY

We will define the term "sensor equivalent visibility" (SEV) as any equivalent of human visibility which is derived from instrumental measurements. This is quite an important concept. In order for a sensor measurement to have meaning, the measurement must be related to some human visibility.

Two distinctly different physical processes are involved in human estimates of visibility (ref. 6), "Daytime estimates of visibility are subjective evaluations of atmospheric attenuation of contrast, while nighttime estimates represent attempts to evaluate something quite different, namely attenuation of flux density..." The human has the advantage of being able to use a combination of both processes in the transition period between day and night. The act of seeing is an extremely complex function. It involves physiological and psychological factors that can, and indeed do, vary widely between observers, and in any one observer at different times.

The first step, then, at deriving an SEV is to relate instrument observations to day/night sensory observations.

4.1 SEV Day

The convention used to translate transmissometer measurements to SEV during day conditions is an application of Koschmieder's Law:

$$\varepsilon = (t_b)^{V/b} \qquad (1)$$

where:

- ε is the observer's contrast threshold,
- t is the atmospheric transmittance
- b is the path length over which atmospheric transmittance is sampled,
- V is the visual range.

The contrast threshold is defined as the smallest contrast of brightness that is perceptible to the human eye based on the brightness and size of the visibility target. As a result of comparisons of human observations with transmittance, the NWS has accepted 0.055 as the value for ε (ref. 7).

Equation (1) is the foundation for the calibration of the transmissometer during day. The same equation is used for day RVV, and for day RVR in the presence of relatively high transmittance conditions. The sensory observation visibility targets are, theoretically, dark objects outlined against the horizon sky.

4.2 SEV Night

The generally accepted convention relating illumination from a point source through an aerosol is Allard's Law. As expressed for converting transmissometer measurements to runway visual range, for example, the equation is:

$$E_m = \frac{I(t_b)^{V/b}}{V^2} \qquad (2)^*$$

where:

- E_m is the pilot's visual illuminance threshold, empirically selected as 1,000 mile-candles, day, and 2 mile-candles, night,
- I is the intensity of the light target (candelas),
- t is the atmospheric transmittance,
- b is the path length over which atmospheric transmittance is sampled,
- V is runway visual range.

Equation (2) is used for night and day RVR when specified high-intensity runway lights are used as the visual range targets. There is a qualification for day RVR; the high-intensity lights must yield greater visual range than nonluminous targets. If not, equation (1) is used.

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*Although this form of Allard's Law expresses RVR in terms of miles, RVR is usually reported in feet.

However, Douglas and Young in their initial work in development of the transmissometer (ref. 3), found another expression that described their experimental data better than did Allard's Law:

$$S_V = \frac{I(t_b)^{V/b}}{V} \qquad (3)$$

where:

- S_V is the observer's illumination threshold, empirically selected as 1.585×10^{-5} lumens/ft.,
- I is a nominal 25-candela light source,
- t is atmospheric transmittance,
- b is the path length over which atmospheric transmittance is sampled,
- V is the visual range.

Equation (3) is used for nighttime RVV and nighttime calibration of the transmissometer. Calibration, however, is usually confined to daytime in routine practice. Nighttime visibility targets for RVV and sensory observations of visibility are, theoretically, 25-candela lights.

5.0 LIMITATIONS OF SENSOR EQUIVALENT VISIBILITY

It is logical to consider the sensory observation as a performance standard for SEV. Unfortunately the human observation of visibility, as indicated earlier, is a weak and arbitrary criterion. Uncertainties in the development of a satisfactory SEV arise from:

a. Empirical constants by which instrument measurements are converted to human equivalents.

b. Degree of representativeness of the visibility sensor data.

c. Doubts about the design of the ideal SEV.

A discussion of items a and b follows. Item c is discussed in the next section of this report.

5.1 Observer's Contrast Threshold (ε).

Reference 6 provides perhaps the most concise explanation of some problems associated with the selection of an optimum value for ε :

> The existence of a finite threshold contrast and its variation with conditions of observation are fundamental factors in the theory of the visual range. Early theoretical work was based on the incorrect assumption that the threshold contrast was a constant equal to about 0.02. If this were true, the visual range would be governed only by the atmospheric extinction. Actually, the threshold contrast varies irregularly from one observer to another under fixed external conditions; it tends to increase with decreasing adaptation luminance, and it also tends to increase with decreasing target visual angle when that angle falls below about one degree. An overall range of about 0.005 to 5.0 must be recognized as existing for the full range of observing conditions.

A field calibration of the NBS transmissometer was conducted in 1941 at Nantucket Island. The prototype sensor was mounted about six feet above ground level. Generally, observers viewed a series of visibility targets consisting of 4-foot-square or 5-foot by 8-foot pieces of plywood painted flat black. Other objects such as church steeples and water towers were also used as visibility markers.

Contrast threshold values were computed from Koschmieder's Law, and 0.055 selected as "... a reasonable representation of the calibration points for the shorter visual ranges" (ref. 3). This value falls between 0.065 for cloud conditions and about half that value for fogs determined by an earlier investigator cited in ref. 3. Douglas and Young noted that the value of 0.055 was most suitable at the lower visual ranges. There was a systematic departure from that value at visual ranges greater than 2 miles.

Beginning in 1951 and ending in 1955 the Weather Bureau conducted a major investigation of visibility and cloud height measurements (ref. 7). A portion of this effort was to assess Douglas and Young's calibration of the transmissometer. The observing program was similar to the earlier program, particularly in requiring nonvarying visibility conditions. However, visibility targets were not standardized, but of the type that might normally be found at an airfield. Observations were mostly made by one individual. The median value for ε was computed to be 0.050.

In 1954 a report was issued giving the results of a disciplined and sophisticated visibility investigation (ref. 8). Standardized targets were used,and the observed data stratified by weather conditions. Median values for ε were determined to be: for radiation fog, 0.065; for snow, 0.030; for ceiling condition 0.042. An extremely limited series of tests in 1966 produced an ε value of about 0.2 (ref. 9). Results were based on visibility targets generally available at an airfield during visibilities of about one mile.

Although the currently accepted U.S. value for ε to convert transmittance to RVR and RVV during day is 0.055, other choices are available. In fact, a review of the literature between 1924 and 1970 reveals that a number of investigators derived values ranging from 0.0077 to 0.2. Translation tables based on a value other than 0.055 would, of course, generate different transmittance/visibility relationships.

5.2 Observer's Illuminance Threshold (S_V).

Problems associated with illuminance threshold are similar to those of contrast threshold. S_V varies from observer to observer and is influenced by the brightness of the background against which the light target is observed. The assumption that the light target is of 25 candelas generally cannot be supported in operational practice.

Douglas and Young developed S_V during the same program in which they calibrated the transmissometer during day conditions (ref. 3). In addition to 25 candela lights mounted atop the standardized visibility targets, other light targets of varying intensities were used.

The Weather Bureau program in the 1950's also assessed the S_V value and concept (ref. 7). The observational program was similar to that for the day evaluation. The final report accepted a median value of 1.585×10^{-5} lumens/ft. for S_V. However, the report went on to say, "... should make clear that although there is doubt regarding the exact mathematical formula to which the calibration curve should be drawn, the general nature of the calibration curve is known, especially in the critical region of 1/2 to 1 mile visibility." And, "The various curves... (other mathematical approaches)... are divergent and yeild appreiciably differing results for the greater visibilities."

There is no NWS calibration for the transmissometer during twilight, although sensory observations of visibility are affected during this period. Since there is a difference in the physical laws which govern the relationship of transmittance and visibility between day and night this situation generates two sets of transmittance-visibility curves. Neither curve is completely suitable for the twilight period.

Most programs for transmissometer calibration and the determination of observer threshold values have acquired the bulk of data in lowered visibility due to fog, haze, and smoke. Comparatively little precise data are available for liquid precipitation conditions and almost none for snow.

5.3 Representativeness of Sensor Data

The transmissometer measures transmittance in a volume limited to the length of the baseline and the optics of the receiver. Sampling depends on the natural movement of the atmosphere through this volume. The information thus obtained, is extrapolated to a value of SEV. The sensor does not "look" in any direction, nor can it sense any element not directly within the sampling volume. Hence, the space and time representativeness of transmissometer data, particularly during nonhomogeneous conditions, is quite uncertain.

In 1958 the Air Force reported on a study of the variations in the horizontal between two transmissometers at Newark Airport, N.J. (ref. 10). The units were about 4,00 feet apart. In their analysis, the researchers wrote, "It cannot be emphasized too strongly that the information obtained from these... instruments applies only to the location of the sensing elements and is true only at the actual time of measurement." They concluded that the variances of simultaneously measured samples of transmittance at the two sites were not statistically equal. Further, that although mean values of transmittance at the two sites did not differ significantly, the difference in individual measurements could be quite high.

A later study by the Weather Bureau for the FAA produced similar results (ref. 11). Four transmissometers were installed along a runway at Atlantic City, N.J. Distances between adjacent units were 1,225, 4,738, and 2,963 feet. Concerned with runway visual range, the report concluded that RVR's obtained from any one transmissometer were not representative of conditions along other sections of the runway.

In 1968 the Weather Bureau ended a test program for the FAA which involved three transmissometer systems in operation at airfields in New York, Chicago, Denver, and Los Angeles. A fifth terminal, Atlantic City, had five systems in operation. Although dealing exclusively with runway visual range, the results concerning sensor siting are applicable to SEV (ref. 12). The report concluded that at least three transmissometer systems were needed along a runway for RVR during very low visibilities due to widely varying conditions. Further, due to siting and sampling limitations, the measurement made by the sensor did not necessarily reflect the identical transmittance encountered by the pilot on the runway. Of particular interest is the conclusion that differences in runway visual range between sensor measurements tended to increase as the distance between sensors increased. Most of the preceding discussion of variations of visibility due to siting has been concerned with horizontal spacing of sensors. Vertical spacing, although less documented in the literature, is of equal importance.

The NBS is analyzing 2 years of transmissometer records to learn the effects of height above ground on transmittance (ref. 13). Three transmissometers were used to measure transmittance along the same 250 foot baseline in Arcata, Calif. The axes of the sensed paths were at 5, 10, and 15 feet above ground. They reported that initial analysis failed to show a simple relationship between height and transmittance. They further stated that in fog conditions the readings of the three transmissometers were seldom in close agreement.

Between March and June 1970 we conducted a limited experiment at SR&DC to obtain information on the variation of visibility with height. Transmissometers were installed at 6' and 15' above ground with a horizontal separation of about 10 feet. Data were collected during periods when the visibility was less than two miles. The following insert shows some results of this experiment:

	Day	Night
Sample size	179	406
Mean difference	0.0	0.0
Standard deviation of differences	0.13 mile	0.34 mile
Correlation coefficient	0.93	0.54
Range of differences	-0.4 to 0.7 mile	-1.4 to 1.6 mile

In the next section of this report processed transmissometer data are compared with prevailing visibility. The problems encountered are typical of any comparison of SEV with a sensory observation. They can be better understood, perhaps, when the examples which follow are considered. These are illustrations of the limitations of SEV when compared to sensory observations during nonhomogeneous visibility.

Figure 2 presents a situation where the usual point of observation is in a static, but relatively small area of low visibility. Here, prevailing visibility is 1/2 mile. SEV, based on the sampling of transmissometer A, would be the same. Transmittance in an adjacent area, however, is much higher. SEV, based on transmissometer B, which is in that area, would disagree with the prevailing visibility in any comparison of the two.

In figure 3, the observer and transmissometer are in a small area of high transmittance in an otherwise low transmittance field. The observer's report, based on his viewing of markers, is 2 miles visibility. The transmissometer, however, samples the atmosphere only within its baseline. SEV, based on this information, would be 10 miles, a physical impossibility in terms of human vision.

Figure 4 illustrates another common nonhomogeneous situation. Here, prevailing visibility is 2 miles based on sector visibilities. As in figure 2, SEV derived from the transmissometer sample would be grossly different from the sensory observation based on the conventions for obtaining prevailing visibility.

The lesson learned from these figures is simple. No visibility sensor can provide information more representative than that of the conditions existing in its own sampling volume at the time the volume is sampled.

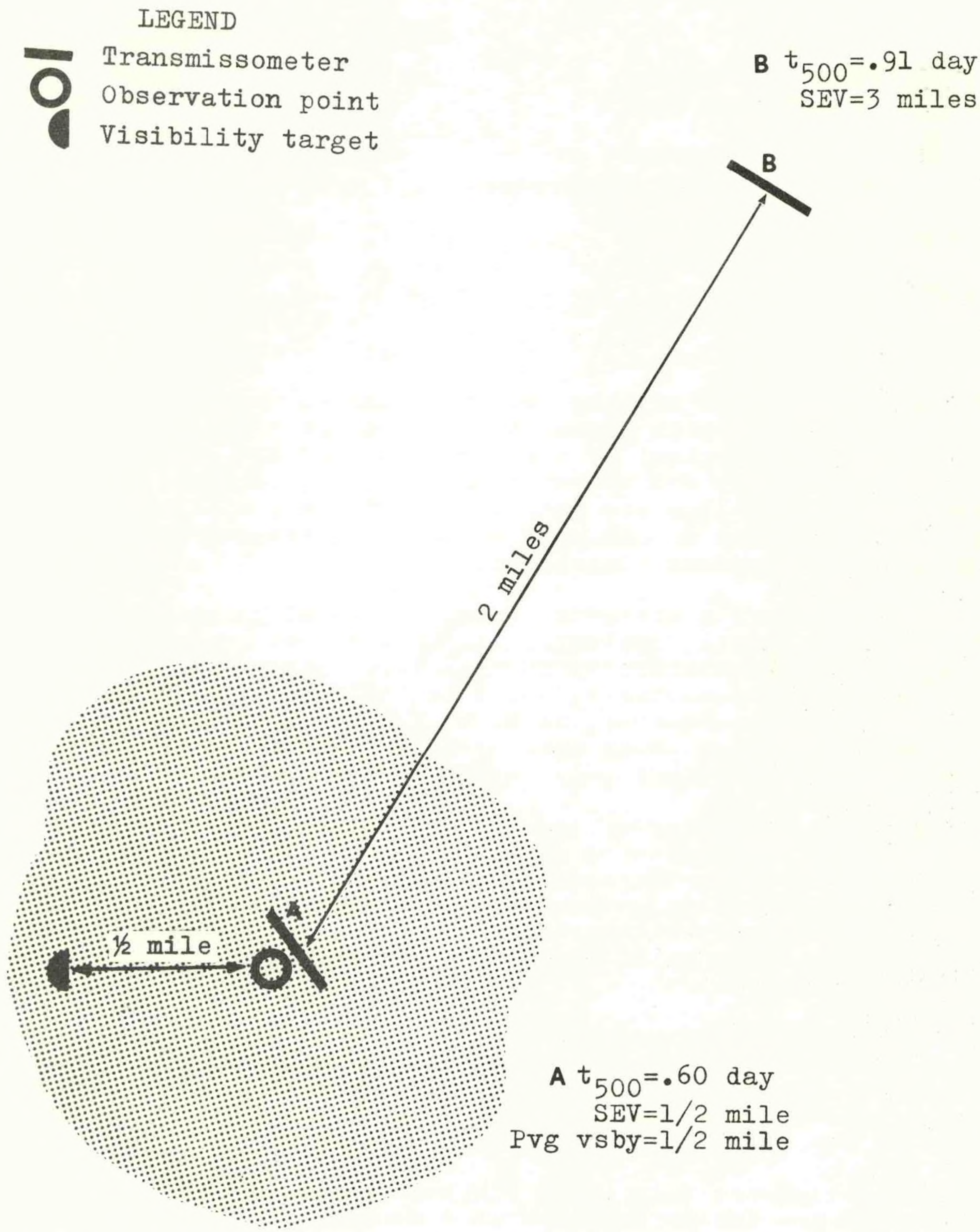

Figure 2.--Limitation of SEV: Observation Point In Area Of Low Transmittance

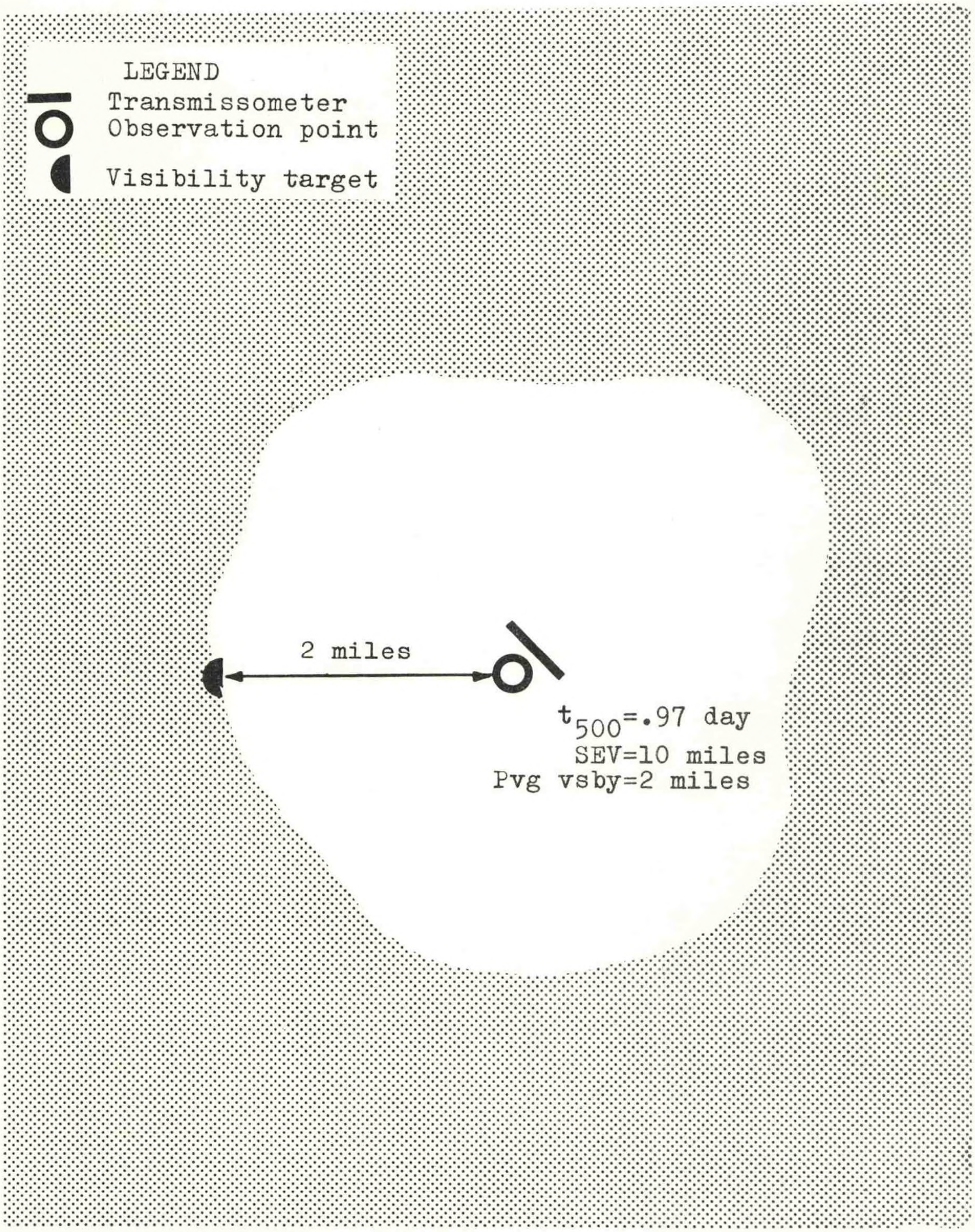

Figure 3.-- Limitation of SEV: Observation Point In Area Of High Transmittance

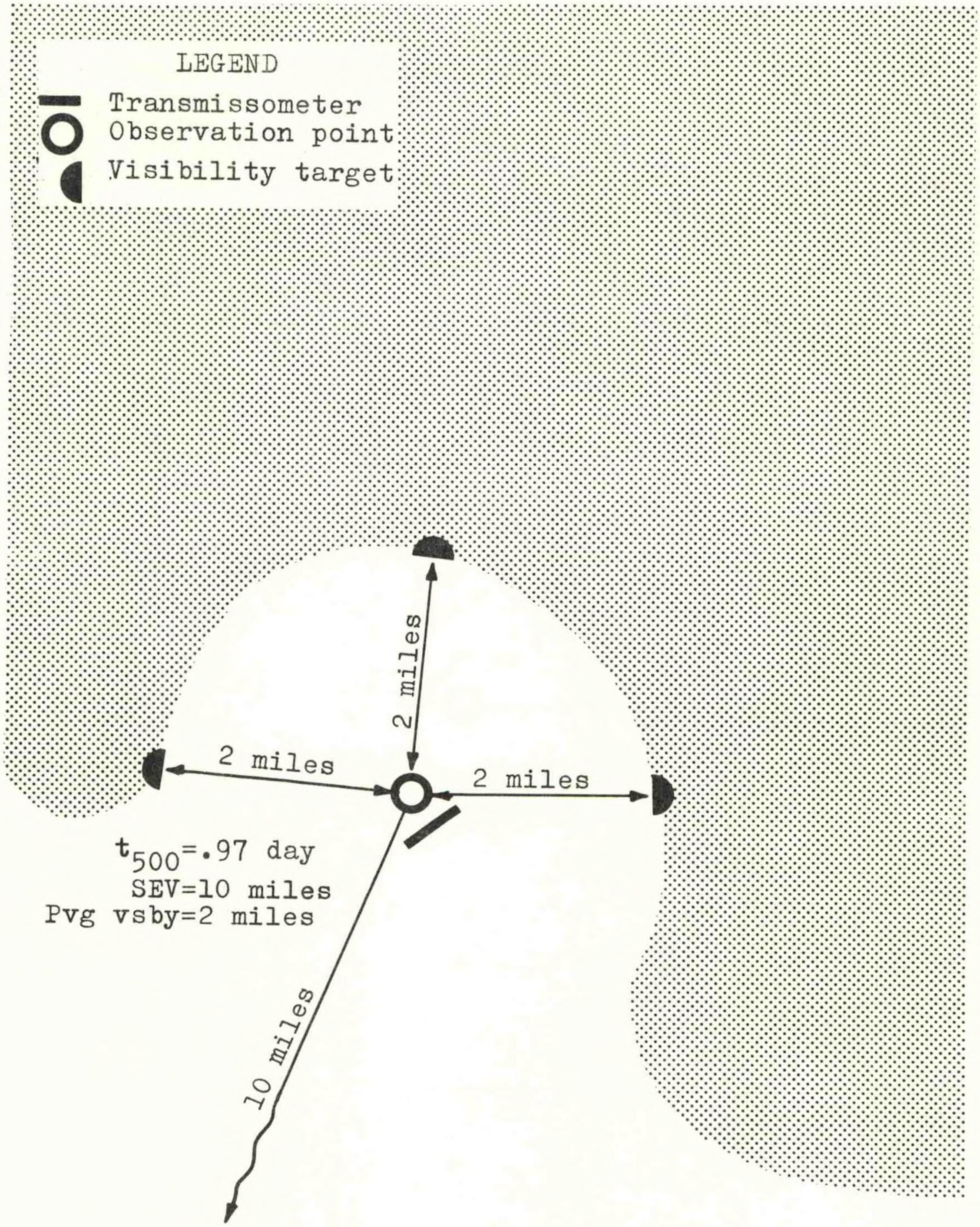

Figure 4.--Comparison of SEV, and Pvg Vsby Based On Sectors

Another important qualification which affects the authenticity of visibility sensor observations must be added here. Time-averaging of instrument output as a processing strategy is usually desirable for reasons of economy and design simplicity. However, arithmetic means may produce fictitious results due to the sampling characteristics of the sensor. Consider the following sequence of 10 one-minute transmissometer pulse counts converted to visibility: 5; 5; 5; 5; 5; 1; 1; 1; 1; 1. Based on an arithmetic mean, visibility would be 3 miles when in fact such visibility did not, or at the most, briefly, existed. In the next section, we will use real data to investigate processing strategy for transmissometer data as well as time representativeness of several SEV's.

6.0 COMPARISON OF SEV AND PREVAILING VISIBILITY

The performance standard usually suggested for SEV is prevailing visibility. Although well defined in FMH #1, many users are unaware of its complexities and limitations in operational practice.

A simulation program was set up to test how well three SEV's, typical of those that might be chosen for automated visibility, would compare with currently defined prevailing visibility observations. We were fortunate in having available detailed transmissometer data coupled with standard airfield prevailing visibility observations. This information obtained in an earlier study, the "3T project," was used as data for comparison.

6.1 Simulation Data - 3T Project

The 3T project, conducted for the FAA during 1966-68, determined the need for three transmissometer systems per runway at special category airfields (ref. 12). The investigation yielded a considerable number of 55-second pulse counts from 250-foot baseline transmissometers located at mid-runway. Sampling was made at five airfields across the continental United States. The stations, distance from station to transmissometer and periods of data acquisition are shown in table 1.

The objectives of the 3T project concerned runway visual range, and emphasis on data reduction was for periods of RVR below 2,400 feet. Not all data were reduced, and there were some small variations in the rules by which data were selected for reduction. As a result, 3T data are but generally representative of low visibility conditions that occurred at the five stations during the sampling period. The data are not inclusive of all low visibility that occurred or were recorded. Nominally, the data reduced were below the equivalent RVV's (equations 1 and 3) of 2 miles by day and 1 mile by night based on transmissometer pulse counts per 55 seconds (adjusted for background count).

Prevailing visibility was taken from the official weather observation of record made at the test-bed stations. Each prevailing visibility observation was the comparison standard for a sequence of transmissometer pulse counts which followed in time. For example, if a prevailing visibility observation was made at 0955, and another was made at 1025, all pulse counts from 0955 until 1025 would be compared with the 0955 prevailing visibility.* Since data reduction was based on RVV, there were no restrictions on extent of prevailing visibility at the time of transmissometer pulse count.

*This time relationship applies to analysis Treatment I (Section 6.2). Treatment II (Section 6.3) minimized time differences between observation and pulse count.

Table 1

Summary of Acquired 3T Project Data

3T Test-Bed Station	Data Collection		Distance Between Pvg Vsby and SEV Observation Points
	Began	Ended	
Atlantic City Airport, N. J. (ACY)	2-1-66	12-31-67	1 mile
J. F. Kennedy International Airport, N.Y., N.Y. (JFK)	4-24-66	12-31-67	1 mile
O'Hare International Airport, Chicago, Ill. (ORD)	6-6-66	12-31-67	9/16 mile
Stapleton International Airport, Denver, Colo. (DEN)	5-9-66	12-31-67	1-1/8 mile
Los Angeles International Airport, Calif. (LAX)	1-18-67	12-31-67	1 mile

There are two effects of uncertain magnitude in this type of comparison. One is that of space--the distance from the point of observation to the transmissometer location. The other is that of time--the period from pulse count to time of prevailing visibility observation. This latter effect, however, can be minimized as done in Section 6.3.

The 3T data were based on 55-second pulse counts. To use them, it was necessary to convert the information to equivalent 1-minute SEV's. The manner in which this was done and the resulting data are shown in table 2, which is based on equation (1) for day and equation (3) for night.

The prevailing visibility data at the test-bed stations were originally recorded in fractional miles as specified in FMH #1. These were converted to decimal equivalents (table 3) for convenient use in the processing strategies. Due to rounding errors, this created several small inconsistencies between fractional and decimal mile increments. The inconsistencies might have a noticeable but minor impact on individual observations but should be undetectable in the aggregate of several months' observations.

The following are definitions of the processing strategies and other, less obvious terms, used in this comparison.

• Pvg vsby: Prevailing visibility, observed according to instructions of FMH #1, valid at the time of the 3T pulse count. When compared with a 10-minute sequence, the pvg vsby in effect at the 10th minute is used. The original fractional visibility values were converted to decimal values (table 3).

• MOS: Mean of several 1-minute pulse counts. Ten consecutive 1-minute pulse counts are each converted to visibility using table 2. MOS is the arithmetic mean of the 10 visibilities.

• TMP: Ten minute pulse count. Transmissometer pulses are counted continuously for 10 minutes. The total pulse count, divided by 10, is translated to visibility (table 2).

• OMV: One-minute visibility. Transmissometer pulses are counted for 1 minute, then translated to visibility (table 2). OMV is nominally equivalent to RVV. When OMV is compared to other processing strategies, it is related to the last minute in any 10-minute sequence.

• Day-night: From sunrise and sunset tables. The day-night condition is based on the time of the first minute in any 10-minute sequence.

Table 2

Translation of 55-Second Pulse Count to Equivalent Visibility (250-foot Baseline)

Visibility (miles)	Pulse Count/55 Seconds			
	Day		Night	
	From	To	From	To
0.0	1	236	-	1
.1	237	1468	2	334
.2	1469	2117	335	958
.3	2118	2477	959	1471
.4	2478	2702	1472	1851
.5	2703	2856	1852	2132
.6	2857	2968	2133	2346
.7	2969	3053	2347	2513
.8	3054	3119	2514	2646
.9	3120	3174	2647	2753
1.0	3175	3218	2754	2842
1.1	3219	3254		
1.2	3255	3285		
1.3	3286	3312		
1.4	3313	3336		
1.5	3337	3356		
1.6	3357	3374		
1.7	3375	3390		
1.8	3391	3405		
1.9	3406	3417		
2.0	3418	3471		

Table 3

Translation of Fractional Miles to Decimal Miles

Fractional Miles*	Decimal Miles
0	0.0
1/16	.1
1/8	.1
3/16	.2
1/4	.3
5/16	.3
3/8	.4
1/2	.5
5/8	.6
3/4	.8
7/8	.9
1	1.0
1-1/8	1.1
1-1/4	1.3
1-3/8	1.4
1-1/2	1.5
1-5/8	1.6
1-3/4	1.8
1-7/8	1.9
2	2.0
2-1/4	2.0
2-1/2	3
3	3
4	4
5	5
6	6
7	7

*From Table A3-4, FMH #1

6.2 Summary of SEV Analysis, Treatment I

Many processing strategies and tests were immediately evident in the preparation of this report. Because of time and economic limitations, only three SEV candidate strategies (MOS, TMP, and OMV) could be accommodated, along with some simple descriptive statistics.

Table 4 summarizes these statistics for the five test-bed stations. In general, the mean difference between pvg vsby and any SEV is small. Larger differences are noticeable, though, during nighttime observations. There appears to be a small bias toward lower pvg vsby as indicated by the many negative valued mean differences.

Standard deviations about the mean indicate fairly large variations, particularly when you consider that data reduction based on transmissometer pulse counts had upper limits of 2 miles day and 1 mile night. About half the standard deviations of pvg vsby minus SEV fall in the range of 1/2 to 3/4 mile, mile, about one-third are greater than 3/4 mile. Most linear correlation coefficients do not evidence strong relationships. Nearly half are less than 0.5. This is true for Total, Day, and Night cases using any of the three SEV's.

In summary then, there is little difference between MOS, TMP, and OMV processing strategies when compared in this manner with pvg vsby. In addition, none of the three SEV's compare well with pvg vsby.

6.3 Summary of SEV Analysis, Treatment II

Problems with the previous analysis include the fact that prevailing visibility observations were not made at the same place, and not often at exactly the same time as transmissometer samples. The distances between the points of observation and the transmissometers (table 1) physically defeat correction of the data for spatial variations. We can, however, reduce the time differences between SEV and pvg vsby.

In this treatment only transmissometer pulse counts between 10 minutes to the hour and on the hour were used. Prevailing visibility was observed at some time during that period so that time differences between pvg vsby and the SEV's were minimized. For convenience, we will refer to this as "on-the-hour" data. The resulting statistics are summarized in table 5.

Table 4

Summary of Descriptive Statistics For Total Data Sample

Combined Day and Night		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.1	-.1	.2	-.0	-.1	-.1
	Pvg vsby-TMP	-.1	-.1	.2	.0	-.1	-.0
	Pvg vsby-OMV	-.1	-.1	.1	-.1	-.1	-.1
Standard Deviation (miles)	Pvg vsby-MOS	.73	.62	.92	.97	.42	.73
	Pvg vsby-TMP	.73	.60	.92	.97	.41	.73
	Pvg vsby-OMV	.78	.66	.95	1.00	.46	.77
Linear Correlation Coefficient	Pvg vsby vs. MOS	.39	.50	.37	.33	.72	.44
	Pvg vsby vs. TMP	.38	.51	.36	.31	.73	.44
	Pvg vsby vs. OMV	.36	.47	.36	.32	.69	.42

Day Only		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.1	.1	-.1	.1	-.1	-.0
	Pvg vsby-TMP	-.1	.1	-.0	.1	-.0	.0
	Pvg vsby-OMV	-.1	.1	-.1	.0	-.1	-.0
Standard Deviation (miles)	Pvg vsby-MOS	.52	.55	.69	.56	.25	.54
	Pvg vsby-TMP	.51	.54	.67	.57	.24	.53
	Pvg vsby-OMV	.57	.58	.76	.61	.26	.58
Linear Correlation Coefficient	Pvg vsby vs. MOS	.43	.50	.48	.68	.79	.51
	Pvg vsby vs. TMP	.42	.51	.47	.66	.81	.50
	Pvg vsby vs. OMV	.39	.46	.47	.62	.78	.47

Night Only		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.1	-.2	.3	-.1	-.1	-.1
	Pvg vsby-TMP	-.1	-.2	.3	-.1	-.1	-.1
	Pvg vsby-OMV	-.1	-.2	.3	-.2	-.1	-.1
Standard Deviation (miles)	Pvg vsby-MOS	.81	.62	1.01	1.20	.50	.82
	Pvg vsby-TMP	.81	.60	1.02	1.20	.49	.81
	Pvg vsby-OMV	.85	.68	1.01	1.23	.54	.86
Linear Correlation Coefficient	Pvg vsby vs. MOS	.37	.55	.36	.14	.71	.41
	Pvg vsby vs. TMP	.36	.56	.33	.13	.72	.41
	Pvg vsby vs. OMV	.35	.52	.36	.15	.67	.39

Table 5

Summary of Descriptive Statistics
For "On-The-Hour" Data Sample

Combined Day and Night		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.1	-.1	.2	.1	-.1	-.1
	Pvg vsby-TMP	-.1	-.1	.2	.1	-.1	-.0
	Pvg vsby-OMV	-.2	-.2	.1	-.1	-.1	-.1
Standard Deviation (miles)	Pvg vsby-MOS	.71	.61	1.06	1.06	.44	.76
	Pvg vsby-TMP	.69	.56	1.06	1.04	.42	.74
	Pvg vsby-OMV	.73	.72	1.03	1.08	.51	.80
Linear Correlation Coefficient	Pvg vsby vs. MOS	.37	.47	.25	.21	.73	.39
	Pvg vsby vs. TMP	.37	.51	.24	.21	.74	.40
	Pvg vsby vs. OMV	.38	.38	.28	.23	.66	.38

Day Only		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.0	.1	-.2	.2	-.0	.0
	Pvg vsby-TMP	-.0	.1	-.2	.3	-.0	.0
	Pvg vsby-OMV	-.1	.0	-.1	.1	-.0	-.0
Standard Deviation (miles)	Pvg vsby-MOS	.43	.53	.84	.52	.23	.53
	Pvg vsby-TMP	.43	.50	.83	.55	.22	.53
	Pvg vsby-OMV	.43	.65	.66	.54	.22	.54
Linear Correlation Coefficient	Pvg vsby vs. MOS	.44	.46	.47	.75	.83	.52
	Pvg vsby vs. TMP	.44	.50	.46	.74	.84	.51
	Pvg vsby vs. OMV	.46	.33	.50	.74	.85	.53

Night Only		ACY	JFK	ORD	DEN	LAX	All
Mean Difference (miles)	Pvg vsby-MOS	-.2	-.3	.4	-.1	-.2	-.1
	Pvg vsby-TMP	-.1	-.2	.4	-.1	-.1	-.1
	Pvg vsby-OMV	-.2	-.3	.3	-.2	-.2	-.2
Standard Deviation (miles)	Pvg vsby-MOS	.78	.63	1.12	1.44	.53	.86
	Pvg vsby-TMP	.77	.57	1.13	1.40	.51	.84
	Pvg vsby-OMV	.82	.75	1.16	1.47	.61	.91
Linear Correlation Coefficient	Pvg vsby vs. MOS	.33	.56	.23	-.02	.71	.34
	Pvg vsby vs. TMP	.33	.56	.21	.01	.73	.36
	Pvg vsby vs. OMV	.34	.42	.22	-.05	.65	.33

The same pattern exists as in Treatment I when comparing pvg vsby with any of the SEV's. The standard deviations are generally large. With a few exceptions, the linear correlation coefficients are not strong. At one location no correlation is present.

Minimizing time differences failed to improve the agreement between pvg vsby and these SEV strategies. We can assume that spatial differences played a role in these results as did other factors, discussed earlier in this report, which influence human observations and processed data obtained from objective sensors.

Sample sizes used in these statistics are noted in the insert below:

Number of Comparisons on Which Statistics Are Based

Total Data Sample

	ACY	JFK	ORD	DEN	LAX	All
Day	5,257	4,144	1,591	1,880	1,764	14,636
Night	11,636	6,589	2,810	2,235	2,845	26,115
Total	16,893	10,733	4,401	4,115	4,609	40,751

"On-The-Hour" Data Sample

	ACY	JFK	ORD	DEN	LAX	All
Day	58	75	27	36	29	225
Night	153	108	48	32	47	388
Total	211	183	75	68	76	613

6.4 Simulation Data - Dulles Project

A transmissometer pulse counter/printer was installed at the Dulles International Airport NWSO. The counter/printer, designed to turn on and off automatically, was connected to a 500-foot baseline transmissometer. The purpose of this data gathering was to expand our SEV data base beyond the nominal 2 mile day/1 mile night limitation of the 3T data.

We chose to sample from the 500-foot baseline transmissometer system on runway 01R. This choice was based upon the 500-foot system's ability to provide better resolution at visibilities above 2 miles than is available from shorter baseline systems. An additional advantage of the 01R system was its clearly visible location 1-3/4 miles south from the prevailing visibility observation site. The location assured us that the prevailing visibility observation would, during most conditions, include the transmissometer area.

We programmed the printer/counter to operate between 10 minutes to the hour and the hour. In general, 10 minutes before the hour coincided with the prevailing visibility observation time and the hour coincided with the nominal recorded observation time. Based upon our experience with 3T simulation, we knew that a 10-minute pulse count analysis provided little more information than a 1-minute analysis. We therefore decided to compute OMV for the first minute count (IMV) and the 10th minute count (XMV). Maximum usable 1-minute pulse counts were limited to 3535 day and 3500 night which correspond to 7 miles RVV (table 6).

This upper limit in itself presents a problem, however. From table 6, you can see just how sensitive visibility is to changes in pulse count, particularly at higher visibilities. This sensitivity, resulting from the visibility conversion algorithm, coupled with the coarseness of transmissometer calibration has given rise to a generally accepted rule of thumb for the upper limit of transmissometer sensed visibility. This rule limits measurements to less than 20 times the instrument baseline, or in this case, about 2 miles. We are, therefore, stretching this principle by exceeding the 2 mile limitation. Similar extrapolations have been proposed as a means of obtaining an index of visibility through use of the transmissometer in the absence of an observer.

Concurrent with each hour's pulse counts, we recorded the IAD prevailing visibility (as with 3T project data, no limit was set for pvg vsby values), current weather, and obstructions to vision. Day/night was determined from sunrise/sunset tables. We gathered data at IAD from early October 1970 through mid-January 1971. A summary of pvg vsby versus SEV analysis is presented in table 7.

Prevailing visibility was, on the average, reported considerably greater than either SEV. Keeping in mind the SEV range of 0 to 7 miles, you can see that fairly large discrepancies occurred between the two observing methods. Standard deviations of the differences were large with moderate linear correlation coefficients. Since the data included many high visibilities, the results are at least partially contributed to by the visibility conversion algorithm noted earlier in this report. We can also

Table 6

Translation of 55-Second Pulse Count to Equivalent Visibility (500-Foot Baseline)

Visibility (miles)	Pulse Count/55 Seconds: Day From - To	Pulse Count/55 Seconds: Night From - To
0.0	0 - 15	
.1	16 - 588	0 - 30
.2	589 - 1222	31 - 250
.3	1223 - 1673	251 - 590
.4	1674 - 1992	591 - 934
.5	1993 - 2226	935 - 1240
.6	2227 - 2403	1241 - 1501
.7	2404 - 2542	1502 - 1721
.8	2543 - 2655	1722 - 1908
.9	2656 - 2746	1909 - 2067
1.0	2747 - 2822	2068 - 2203
1.1	2823 - 2888	2204 - 2320
1.2	2889 - 2943	2321 - 2422
1.3	2944 - 2992	2423 - 2511
1.4	2993 - 3034	2512 - 2589
1.5	3035 - 3071	2590 - 2658
1.6	3072 - 3105	2659 - 2721
1.7	3106 - 3134	2722 - 2777
1.8	3135 - 3161	2778 - 2826
1.9	3162 - 3184	2827 - 2872
2.0	3185 - 3285	2873 - 3059
3	3286 - 3390	3060 - 3251
4	3391 - 3449	3252 - 3357
5	3450 - 3488	3358 - 3423
6	3489 - 3514	3424 - 3468
7	3515 - 3535	3469 - 3500

Table 7

Summary Of Descriptive Statistics:
Dulles International Airport

Combined Day and Night: 1,225 Comparisons

Mean Difference (miles)	Pvg vsby-IMV	4.1
	Pvg vsby-XMV	4.1
Standard Deviation (miles)	Pvg vsby-IMV	5.16
	Pvg vsby-XMV	5.19
Linear Correlation Coefficient	Pvg vsby vs. IMV	.57
	Pvg vsby vs. XMV	.56

Day Only: 568 Comparisons

Mean Difference (miles)	Pvg vsby-IMV	5.4
	Pvg vsby-XMV	5.4
Standard Deviation (miles)	Pvg vsby-IMV	5.80
	Pvg vsby-XMV	5.88
Linear Correlation Coefficient	Pvg vsby vs. IMV	.51
	Pvg vsby vs. XMV	.48

Night Only: 657 Comparisons

Mean Difference (miles)	Pvg vsby-IMV	3.0
	Pvg vsby-XMV	3.0
Standard Deviation (miles)	Pvg vsby-IMV	4.23
	Pvg vsby-XMV	4.22
Linear Correlation Coefficient	Pvg vsby vs. IMV	.67
	Pvg vsby vs. XMV	.67

assume that calibration errors and errors in estimates of visibility, as discussed in Section 2.0, played a major role particularly in the magnitude of the standard deviations. It appears that neither IMV or XMV closely approximates pvg vsby. In addition, there seems to be no basis for preferring either SEV.

6.5 Summary of Results

None of the SEV's tested are representative of pvg vsby for the data examined. This is a consequence of the many factors affecting SEV and pvg vsby observations. For SEV's these include, but are not limited to time and space considerations, processing algorithms, sensor calibration errors, and the conventions by which transmissometer measurements are converted to the equivalent of human visibility. For pvg vsby the major factors include the number and location of visibility markers at the observing site, the psycho-physical character of the human subjective observation, and errors in visibility estimates.

There is little difference in the statistical characteristics between the SEV's and between SEV's and pvg vsby. Minimizing time differences between pvg vsby observations and SEV's yielded no greater agreement. This indicates the relative unimportance of time considerations and the processing algorithm relative to the other factors which influence visibility observations.

GLOSSARY

ACY	Atlantic City Municipal Airport, Atlantic City, N.J.
Day	Ambient illumination 3 foot-candles or greater
DEN	Stapleton International Airport, Denver, Colo.
FAA	Federal Aviation Administration
FMH #1	Federal Meteorological Handbook #1, Surface Observations
IAD	Dulles International Airport, Washington, D.C.
IMV	1-minute visibility at minute 1. Transmissometer pulses are counted for 1 minute and then transmitted to visibility. Nominally equivalent to RVV.
JFK	J. F. Kennedy International Airport, New York, N.Y.
LAX	Los Angeles International Airport, Los Angeles, Calif.
MOS	Mean of several 1-minute pulse counts. Ten consecutive 1-minute pulse counts are each converted to visibility. MOS is the arithmetic mean of the 10 visibilities.
NBS	National Bureau of Standards
Night	Ambient illumination less than 3 foot-candles
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NWSO	National Weather Service Office

OMV	1 minute visibility. Transmissometer pulses are counted for 1 minute and then translated to visibility. Nominally equivalent to RVV
ORD	O'Hare International Airport, Chicago, Ill.
Pvg vsby	Prevailing visibility observed according to instructions of FMH #1, valid at the time of the pulse count. When compared with a 10-minute sequence, the pvg vsby in effect at the 10th minute is used. Fractional visibility values were converted to decimal values.
RVR	Runway visual range
RVV	Runway visibility
SEV	Sensor equivalent visibility
SR&DC	Sterling Research and Development Center, Sterling, Va.
TMP	10-minute pulse count. Transmissometer pulses are counted continuously for 10 minutes. The total pulse count, divided by 10, is translated to visibility.
XMV	1 minute visibility at minute 10. Transmissometer pulses are counted for 1 minute and then translated to visibility. Nominally equivalent to RVV

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