



The Case for Forward Scatter Sensors for CAT 1 & CAT 11 Runways



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**Using Forward Scatter RVR systems
for CAT 1 & 11 runways.**

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Using Forward Scatter RVR systems for CAT 1 & 11 runways.

1. Forward

A number of papers have been published comparing Forward Scatter meters to Transmissometers for the purposes of determining Meteorological Optical Range (MOR). This paper focuses on the application of these devices to automatically determine Runway Visual Range (RVR). It will be of interest to airport operators with CAT 1 and CAT 11 runways looking to automate RVR measurements.

To determine RVR requires a calculation of the visibility and other visibility related parameters. This paper sets out the case to use Forward scatter meters in airports with CAT 1 and CAT 11 runways. It shows that there are errors in calculating the visibility related parameters and the assumption that a Transmissometer is the best instrument to determine RVR for CAT 1 and CAT 2 runways is an expensive one.

The paper describes in straightforward terms visibility and the other parameters required to determine RVR. It also sets out specific data gathered from a comparison trial of a Transmissometer and a Forward Scatter meter in determining RVR. The final section is a business case that shows that a Forward scatter meter is the most cost effective solution for CAT 1 and CAT 2 runways.

2. Runway Visibility

Runway visibility is one of the key parameters that a pilot requires before landing the aircraft. To provide a runway visibility reading, three methods are used.



- ❖ Human observers
- ❖ Automatically using Transmissometer measuring instruments
- ❖ Automatically using forward scatter measuring instruments.

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- Human observers are as the name implies humans looking at runway lights.
- A Transmissometer is a sensitive light measurement instrument.
- Forward scatter instruments are another way of measuring light.

Runway visibility is not only a measure of the light transmittance; there are other equally important parameters which are used to calculate runway visibility.

3. Light issues

3.1. Visibility

Horizontal visibility through the atmosphere is determined by the presence of particles which cause light to be scattered. For light in the visible and near visible part of the spectrum, scattering occurs by suspended particles such as fog droplets, dust and smoke particles. Scattering also occurs with raindrops, drizzle droplets, snowflakes and hailstones.



RVR is determined by viewing a distant object or light source. Two processes affect the visibility of the object and light source, light scattering caused by the atmospheric particles and stray light from other sources. These processes respectively reduce the apparent light intensity reaching an observer and added stray light causes a reduction in the apparent contrast between the distant object or light source. As a consequence of these effects visibility is determined by the concentration and type of scattering particles present in the atmosphere.

Scientifically these effects are quantified and the term extinction coefficient is given to the measurement of visibility. As one might assume, on clear days the extinction coefficient (EXCO) will be low, but high on occasions where there is dust or high amounts of moisture present. Another important parameter in RVR calculations is the Meteorological Optical Range (MOR). This is defined as the length of a path through the atmosphere that attenuates a beam of light to 5% of its original intensity. The significance of MOR is that it can be measured.

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3.2. Measuring Visibility

Forward scatter meters provide a measurement of EXCO. A physicist called Koschmeider, in the early 1920's made a study of atmospheric visibility and discovered that there was a relationship between MOR and EXCO. His findings enabled him to derive an equation, subsequently called Koschmeider's law, which determined that $MOR = 3/EXCO$. It is this relationship which is fundamental to the use of forward scatter meters in the calculation of RVR.

Koschmeider's law is fine for measuring visibility during the day, but airports work around the clock. For night time visibility the human eye needs to distinguish light sources against a dark background and the contrast threshold of the eye changes under dark conditions.

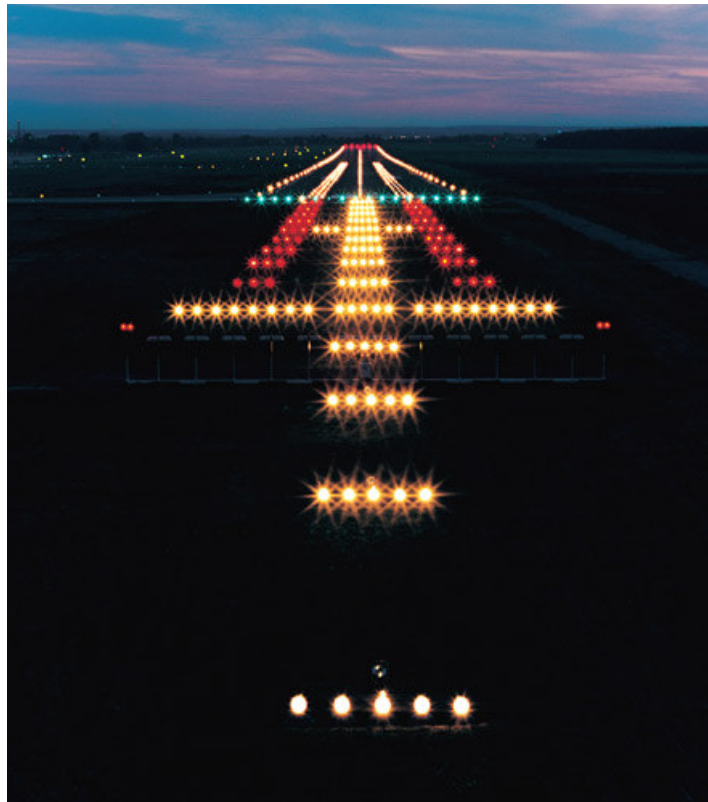
In the mid 19th century a gentleman called Mr Allard derived an equation for measuring visibility during the night.

With mathematics to determine day and night time visibility there are two further factors that need to be considered to calculate RVR. These are the illumination of the runway lights and the illumination threshold of the eye.

4. RVR Systems

4.1. Human Observers

Before automation RVR was determined by a human observer. The job entails standing on a platform adjacent to the runway touch down zone and counting the number of opposite side runway edge lights visible from the observation point. The number of lights visible was relayed to the Air Traffic Controller (ATC) and was converted to a value for RVR using a look up table. The table was generated by a qualified meteorologist who produced the table and updated it every three years for the specific airport. As air traffic has dramatically increased over the last 20 years, flying in all sorts of conditions, human observers would not be efficient or cost effective for a major airport.



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4.2. Transmissometers

The measurement of Runway visual range has typically been measured with an instrument called a Transmissometer. This measures the transmission of a reference light beam and compares it with a beam of light that has travelled a specific distance through the atmosphere. The resulting value, measured with a photodiode is called transmission.

4.3. Forward Scatter Instruments

Scientifically called a nephelometer, a forward scatter sensor measures the amount of light scattered at angles less than 90 degrees by small particulates suspended in, or large particles passing through its sample volume.

The sample volume is defined by the intersection of the transmitted beam of light and the ray cone, which defines the field of view. This is shown in fig 1

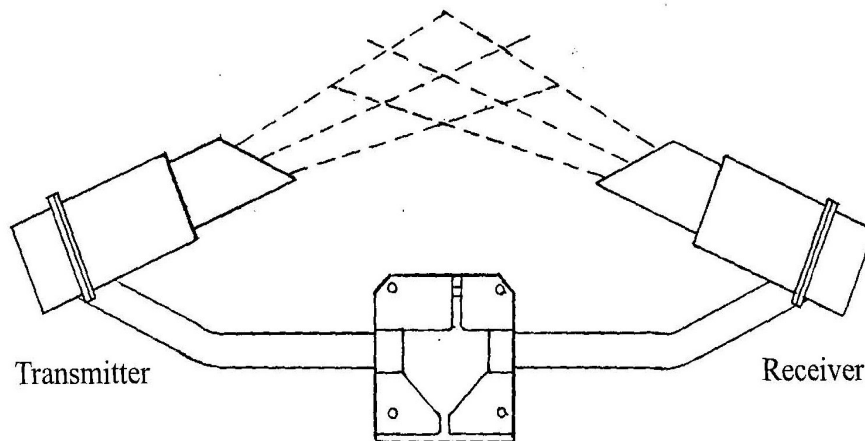


Figure 2-1. Top view of the Sensor Head.

Figure 1 Biral Sensor field of view

Considering the physical constraints in measuring visual range and relating the reality of how the human observer method worked, it is clear that there can be no specific measurement of RVR, rather it is an assessment. This is how RVR is defined by the International Civil Aviation Organisation (ICAO).

RVR is the range over which the Pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line.”

At the eighth air navigation conference held in Montreal in 1974 this definition was modified to read **“RVR cannot be measured directly on the runway an RVR observation should be the best possible assessment of the range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line.**

The key statement that stands out is the best possible assessment.

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5. Assessment of Runway Visual Range

Assessing the Runway Visual Range involves measuring a number of parameters as follows:

- ❖ Extinction Co efficient β (measured by the forward scatter sensor)
- ❖ Background Luminance measured using a photodiode viewing a portion of the north sky to determine the ambient light level.
- ❖ Runway lighting value, a measure of the amount of current taken by the runway lights. This value is taken from a restricted number of settings from the maximum current. The settings are at 1%, 3%, 10%, 30% and 100%

Each of these parameters has an associated error attached to it. A respected meteorologist Dr Alan Hisscott has investigated the use of Forward Scatter meters and carried out a number of trials in the early 90s on the Isle of Man. Dr Hisscott has written and presented a number of papers to the Royal Met Society concentrating on the scientific comparison of Transmissometer and Forward Scatter sensor performance. From his trial results he has quantified the errors in each of the RVR parameters.

5.1. RVR Parameter issues

The luminance parameter is certainly influenced by the ambient airport environment. From results of a trial of forward scatter sensors in 2001, Dr Hisscott had noticed a difference in luminance values between two background luminance monitors (BLM) located at different parts of the airport. With no change in visibility Dr Hisscott found that the difference in the two sensors was caused by the runway lighting.

It is evident that taking five specific values for the runway illumination must introduce errors into the assessment and both Dr Hisscott and others estimate that the runway lighting value could be in error by 50% due to lamp aging and contamination.

Dr Hisscott has summarised the errors attributed to the runway lights and background luminance as well as the pilots view through the planes wind shield. These are set out below.

Parameter	ΔRVR
Runway Light intensity	10%
Background luminance monitor	6%
Windshield transmittance	10 – 30%

These errors are discussed further in Section 6 with the comparison data of a Transmissometer and a Forward Scatter meter.

5.2. Sensor contamination

One of the other issues with calculating RVR is the build up of contamination on the glass window surfaces of the sensor and light transmitter housings. This is a whole topic in its own right. In this paper we limit our discussion to point out that most RVR systems have additional sensors and software to detect window contamination, and they can both compensate for it as well as sending warning messages to the operators. In this way contamination can be managed, but it is a factor that will be different with each installation and airport.

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6. AGI RVR Comparative tests of a Transmissometer and Forward Scatter

AGI's Transmissometer design, the AGIVIS 2000, has been in use for over 20 years. It has proved its accuracy and reliability both in bench mark trials and importantly in operational use. The AGI Forward Scatter RVR system was developed in 2005 and in 2006 AGI ran a trial of a Forward scatter RVR system using the Biral VPF 730 sensor against an installed AGI AGIVIS 2000 Transmissometer at Birmingham Airport.

The trial data was analysed by mathematicians and Meteorologists. Dr Hisscott was also sent a copy and his findings are set out below.

6.1. AGI Birmingham Trial Data

The following is an extract from the paper that Dr Hisscott produced for AGI

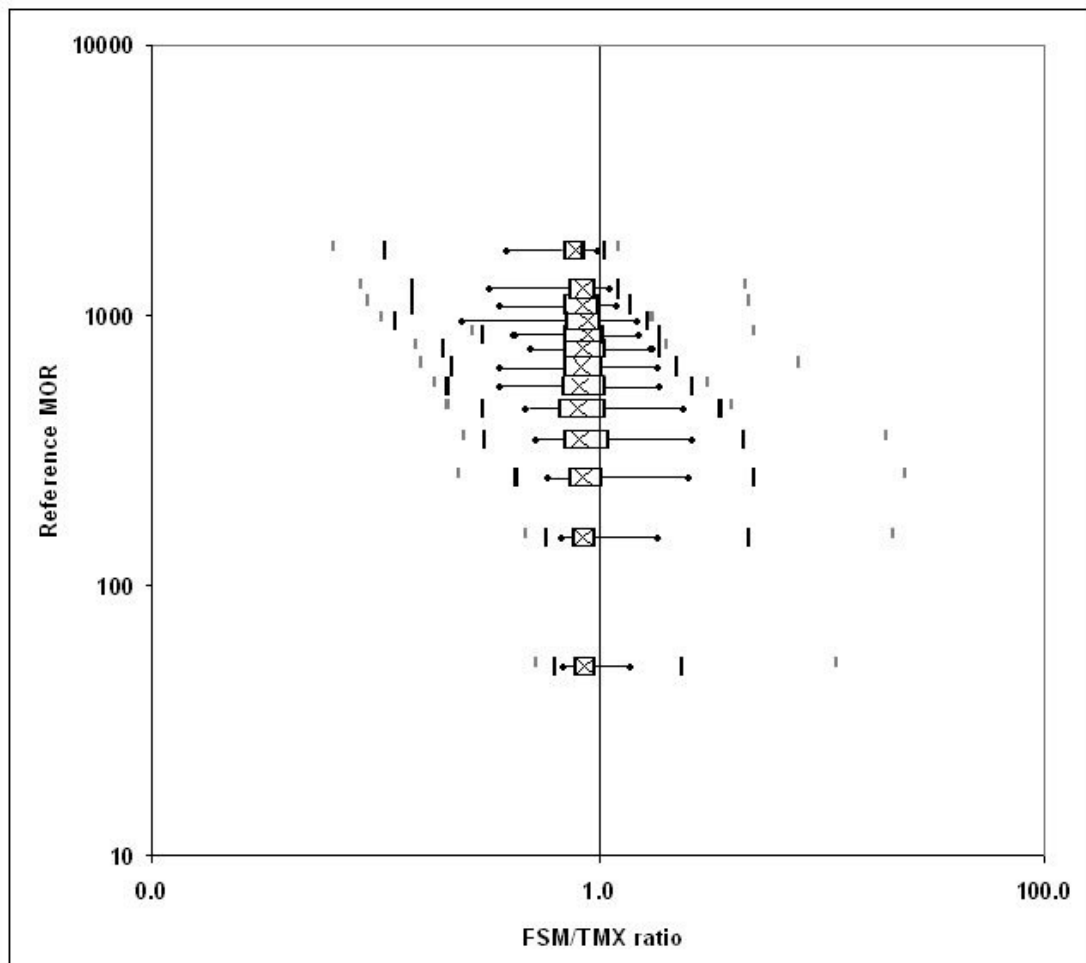


Figure 6 : The data set was reduced to occasions when both the FSM and TMX were reporting valid RVR values.

The difference between the complete set of values and the set analysed in Figure 6 suggests that the apparent increase in FSM MOR in the region 1000-1500m arises from the instruments having a different response to transient conditions. MORs in this range often corresponds to transition visibilities during fog formation and dispersal. The difference between the instruments is probably fundamental to their design. The volume of atmosphere sampled by a Transmissometer (say 10m beam length x 0.05m² X-section = 500 litres) whereas FSM sample volume is usually around 3 litres. Also, the geometry of the sample volume is very different. During the formation/dispersal process of fog there are large spatial variations in droplet density over small ranges. The TMX beam has a higher probability of

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'capturing' one or more 'wisps' of inhomogeneous fog during a measuring interval than the smaller sample volume of an FSM. However, it is likely that during such transient conditions neither instrument can measure an MOR sample which is truly representative of conditions along a runway.

The most important part of the RVR range for Cat I operational decisions is around 400-800m and the average median ratio in this range is 0.83 i.e. the FSM reports MOR around 17% less than TMX in this range. Although it is possible to modify the calibration of FSMs to match the median of TMX, my view is that, at this stage of adopting FSM technology, it is probably better to retain the 'safe' bias where around 75% of the FSM MOR measurements are equal to or less than the equivalent TMX MOR.

For a CAT 11 runway the runway visual range should not be less than 350 m. For CAT 1 it is 550m. The trial data shows the same median values at both these visibility ranges. The difference in the ICAO's recommendations is that a second sensor at the mid point is required for CAT 2 runways.

Dr Hisscott's conclusions from the Birmingham trial data were as follows:

- A median difference in MOR between the Transmissometer and the Biral sensor was -13%
- This is consistent with the other errors in IRVR calculations.
- The type of sensor used to measure the MOR does not contribute a more significant error than the overall error arising from the other parameters.

7. A business case for Forward scatter RVR Systems

The previous sections have set out the case to use Forward scatter RVR from a technical viewpoint but there are economic drivers as well. The following is a sample business case to use Forward scatter sensors.

There are significant price differences between a Transmissometer and a Forward Scatter RVR system for a CAT 1 or CAT 11 runway. The examples are for a two position system. Figures were gathered from the web and market intelligence and the chart in Fig 2 shows this comparison, the currency used was Euros.

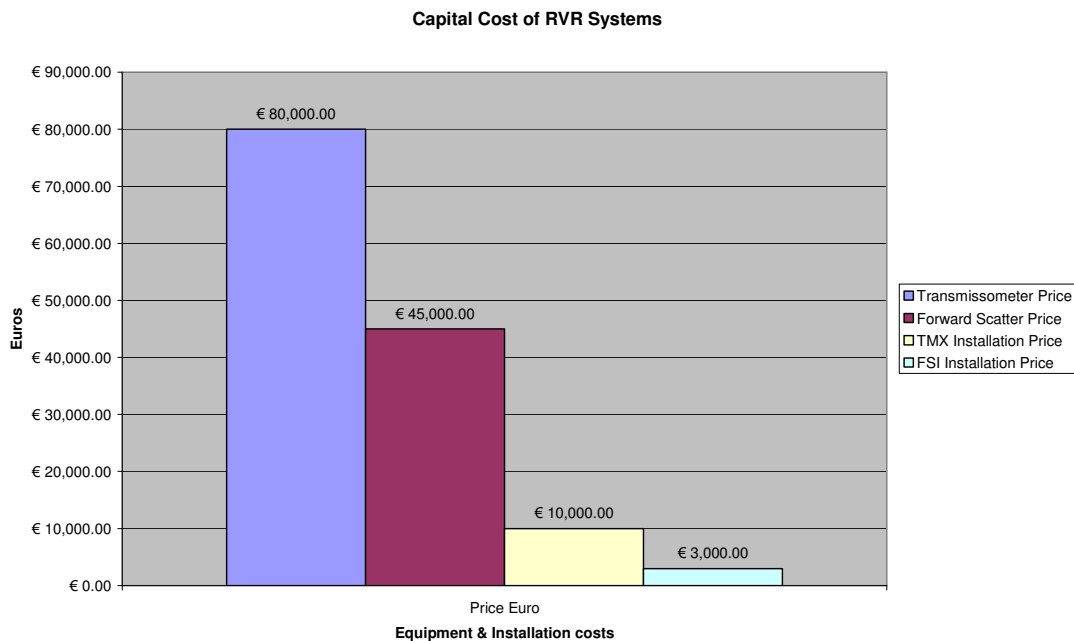


Figure 2 Capital cost of Transmissometer Systems versus Forward scatter for 2 sensors

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Justifying an automated RVR System instead of human observers can be economically justified and again from real world examples the figures include annual costs and expenses.

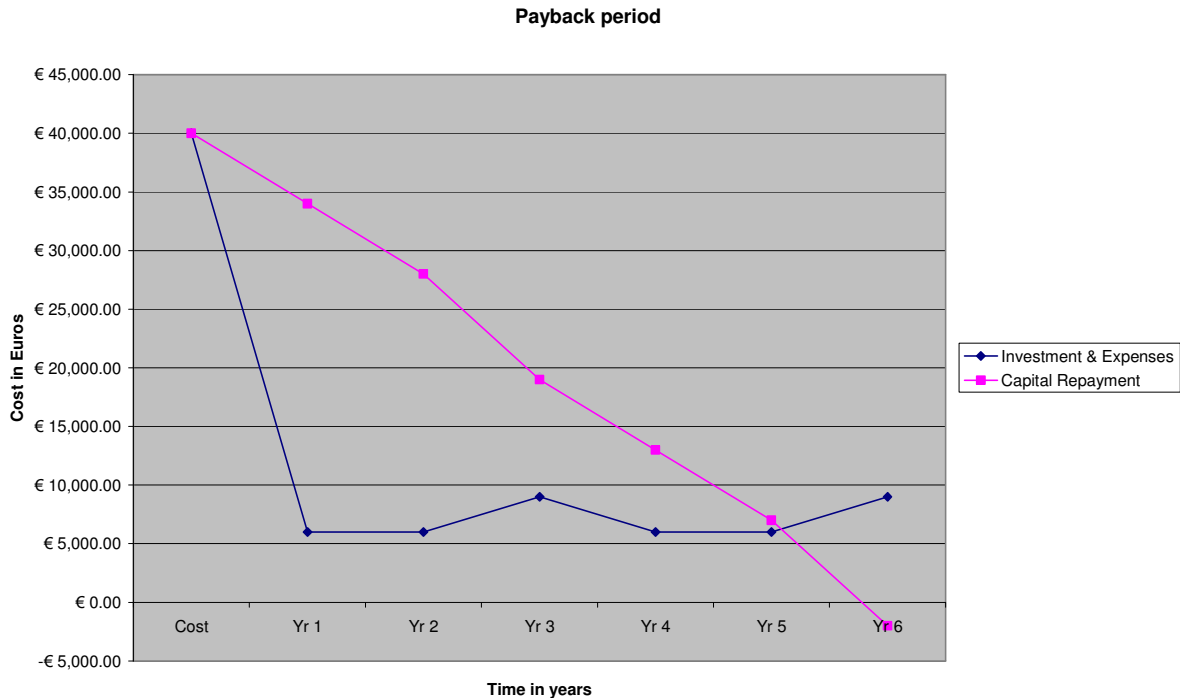


Figure 3 Simple payback period graph

The costs were estimated from the following

- A man year 30,000 Euro
- A month of foggy days 2500 Euro
- The costs of two people one for RVR and one to inspect the runway plus fuel and other expenses Total 6000 Euro.
- An additional refurbishment cost every 3 years for the RVR accommodation and facilities 3000 euro.

Taking a simple payback view the capital cost is repaid after 6 years and 9months.

	Cost (Euro)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Capital & Expenses	40,000	6000	6000	9000	6000	6000	9000
Repayments	0	34000	28000	19000	13000	7000	-2000

This simple payback analysis does not provide an attractive business case for the finance department. The key drivers for automating RVR are from the safety viewpoint. Safety and risk management are critical measures for a well managed airport. Using an automated RVR system increases the margin of safety and will reduce the risks to personnel who have to manage the runways.

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The following are some of the safety issues that an automated RVR system will address over human observers.

- FSRVR generates a visibility reading automatically there is no error in the ATC converting a reading from the observer.
- No human errors interpreting the readings
- FSRVR responds immediately to changes in visibility.
- The risk with vehicles driving and parking near the runway in LVP conditions is eliminated.

8. Summary

This paper shows that Forward Scatter RVR systems are safer to use than human observers and that for an Airport with CAT 1 and CAT 2 runways, offer a more cost effective solution than a Transmissometer system.

Thanks to Alan Hisscott the Senior Meteorological Officer of the Isle of Man Met office for allowing us to use his research findings.

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