the total width between the outer edges of the two inner lanes was increased from 10 miles to 24 miles. Off Casquets the total width between the outer edges of the traffic lanes was increased from 8 miles to 15 miles.

The changes made in January 1979 have almost certainly caused an increase in the frequency of broad crossing encounters, but are likely to have reduced the frequency of the much more dangerous meeting and fine crossing encounters in the area between the two separation schemes. A clear indication of the effect of the changes may be obtained from the collisions recorded in *Lloyd's Weekly Casualty Reports*. As Dr Kwik has pointed out, collisions involving only minor damage may not be reported, but collisions between vessels over 100 tons proceeding on passage in the open sea are unlikely to involve negligible damage, so reliable statistics can be obtained for areas such as the English Channel.

The TSS off Ushant and Casquets were established in 1968. In the 11-year period 1968–1978 fourteen collisions were reported between vessels proceeding in opposite directions, and one between vessels going in the same direction in the area between the TSS. No collisions were reported between vessels likely to have been crossing at a broad angle.

During the 6-year period 1979–1984 only five collisions between vessels of over 100 tons proceeding on passage were reported in the same area. Three of these were between vessels proceeding in opposite directions and two were between vessels going in the same direction. So far there has apparently been no report of a collision involving a tanker proceeding from the outer lane of the Ushant TSS towards Casquets and a vessel proceeding from the Casquets TSS towards Ushant.

It is not claimed that the above results provide conclusive proof that there has been a reduction of the danger of collision in the sea area west of Casquets, but the measures to reduce the incidence of meeting or fine crossing collisions appear to be proving effective, and the consequences of increasing the number of crossing encounters have not been as disastrous as sometimes predicted.

Dr Kwik replies

The paper deals with the prediction of rare events. Because ship collisions are relatively rare events, collision statistics (perhaps I should say historical collision data) are less suited as a basis for the calculations. Instead, the use of mathematical simulation derived from the principles of systems engineering has been appealed to.

In fact, there is no advantage in the historical data method over simulation for our purpose. The knowledge that a number of collisions, say 14, has occurred within a given period, say 20 years, is of little value. Those 14 collisions could in fact have been bunched together within a few years only, whilst a sequence of years failed to yield a single casualty. It is also very unlikely that we would include 7 collisions within an arbitrary 10-year period. In other words, the mean value depends not only on the chosen duration of the time interval, but also on its position on the time axis. This is a serious difficulty known to statisticians when dealing with rare events.

Let us assume casualty records show that there have been 9 collisions in the 10-year period beginning 20 years ago and 5 collisions in the following 10-year period. We would not be in a position to specify why this is so because the change might be attributable to many reasons in the course of time; nor would we be able to say what the collision

probability would be in the near future. Answers to these questions can be given by the simulation.

I know no fundamental shortcoming associated with the mathematical simulation. Human factors have been taken into account in the mathematical approach described in the paper. All relevant factors appearing in real life and not only those mentioned by Captain Cockcroft should be included in a properly derived simulation model. These factors are given as probability density functions to cover the uncertainties of their occurrence, and the collision probability can be calculated as a function of these factors, be it retrospectively or prospectively. Mathematical modelling in association with probabilistic techniques is such a powerful tool in the modern science of safety that it would be unwise not to use it. The difficulty we have at present is that we do not yet have sufficient measured data (particularly concerning human behaviour) to carry out the calculations properly. But this deficiency can be removed by further investigations and does not impair the strength of the method.

My remarks on the collision rates between the Casquets and Ushant schemes only served to illustrate the use of the method and were necessarily only a very shortened account of the results of a Report. The values given in Table 1 b are as predicted by calculation. The column headed ' Without crossings' gives the collision rates if all crossing encounters *including* fine crossings were left out of account. The ' considerable increase due to crossings' refers to comparison with the column headed ' With crossings before scheme modification', where the collision rate has increased in the first place due to fine crossings which were *observed* to take place between vessels bound for southern English ports and the traffic proceeding between the two schemes.

Before the scheme modification a proportion of ships sailing to and from southern English ports left and joined the traffic streams south of the Ushant scheme. Some shipmasters obviously deliberately made a small detour to avoid crossing the traffic streams between the Ushant and Casquets schemes. They seemed to stop doing so after the schemes were shifted north-west. The collision rate in the column headed ' With crossings after scheme modification' has further increased due to the increased number of fine crossings caused by the ships bound for southern English ports, and due to the additional fine crossings caused by the vessels using the third lane of the Ushant scheme which were *observed to* take place between the two schemes despite the sailing recommendations. One conclusion of the study has been that the collision rate cannot be estimated on grounds of isolated factors such as traffic density, ship speeds, encounter angles, ship manoeuvrabilities, etc., alone, but should be calculated considering all relevant factors.

The collision data presented by Captain Cockcroft for the area between the Ushant and Casquets schemes cannot be used to ' prove' anything for the reasons mentioned earlier. Nor can his view that ' the measures to reduce the incidence of meeting or fine crossing collisions appear to be proving effective' be accepted without further investigation.

11-2