Decision Tool for optimal deployment of radar systems

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1. SUMMARY

A Decision Tool for air defence is presented. This Decision Tool, when provided with information about the radar, the environment, and the expected class of targets, informs the radar operator about detection probabilities. This assists the radar operator to select the optimum radar parameters. In the future, a Decision Tool will be developed that advises the radar operator about the optimum selection of radar parameters.

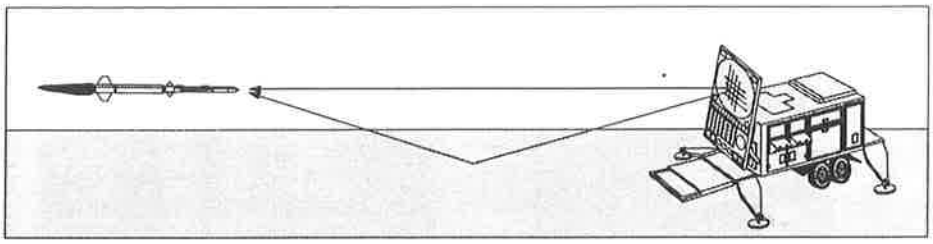

Fig. 1: Multipath.

2. INTRODUCTION

In many cases, a radar operator has more than one radar system at his disposal in order to search for approaching targets. These systems may differ largely with respect to transmitted power, antenna gain, frequency, polarization, noise figure and signal processing. Further, for each radar system, the operator can choose some parameters like pulse repetition frequency, pulse length, frame time, etc. Which radar system and which set of parameters will yield the largest possibility of detection depends heavily on the actual propagation conditions (ducting!), on the target that is expected (altitude, velocity), and on the clutter from the environment.

TNO-FEL has developed a computer program called PARADE that, provided with a set of radar parameters and actual meteorological conditions, calculates radar coverage diagrams as a function of range and altitude. The program can also compute detection probabilities as a function of range and altitude for a given target radar cross section and velocity. It is based on the program described in [1]. Some examples will be shown, displaying the capabilities of PARADE. PARADE is currently being extended to a Decision Tool, which can advise the operator which radar system to use and which parameters to select.

3. DECISION TOOL

As has been pointed out in the introduction, the performance of a radar system depends not only on the set of parameters chosen by the radar operator, but also on the environmental conditions and on the class of targets that is expected.

Among the environmental conditions that influence the radar performance are multipath and ducting. Multipath is the well-known phenomenon that the radar signals travelling from the radar to the target follow several paths: the direct path, and one or more paths via the ground or via obstacles (Fig. 1). Arriving at the target, these signals interfere with each other, resulting in either increased or decreased total signal strength. Whether ducting occurs depends on the way the index of refraction n of the atmosphere changes with altitude h. This in turn depends on the temperature profile, the relative humidity and the wind speed. Whether ducting occurs can be determined easily from the dependence of the modified refractivity M with altitude. The modified refractivity is defined as

$$M(h) = (n - 1 + h/a)\times 10^6 ,$$

where a is the radius of the earth. When there is a layer in the atmosphere in which M decreases with increasing altitude, ducting occurs, and part of the radar signal is trapped in the duct. Four types of duct are illustrated in figure 3.

Apart from trapping, superrefraction, subrefraction or standard propagation may occur (Fig. 2), depending on the exact meteorological conditions that determine the refractivity profile.

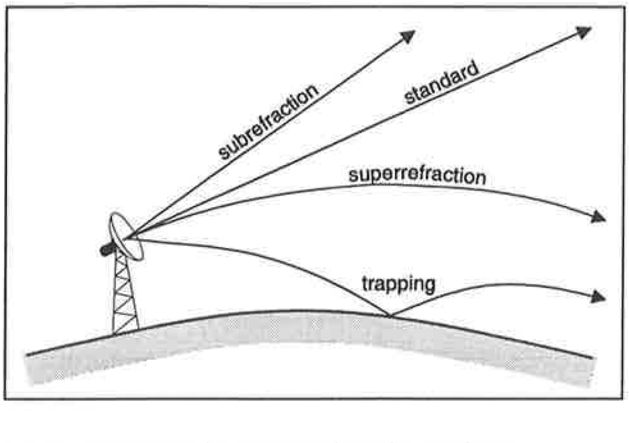

Fig. 2: Wave paths for various refractivity conditions.

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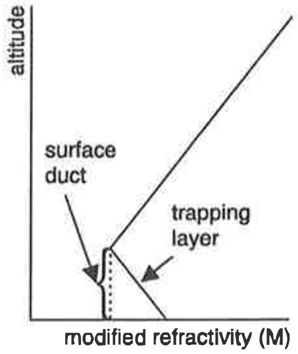
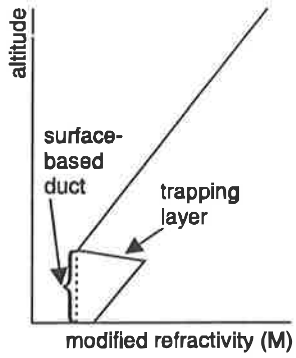
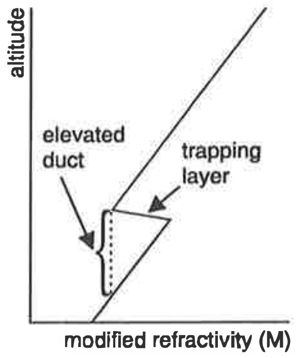


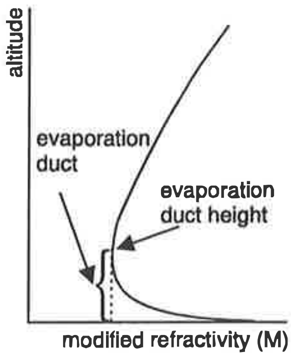
a. Surface duct formed by a surface trapping layer.



b. Surface-based duct formed by an elevated trapping layer.



c. Elevated duct formed by an elevated trapping layer.



d. Evaporation duct formed by a decrease of humidity immediately adjacent to the sea surface.

Fig. 3: Examples of atmospheric ducts.

The combination of multipath and duct may give rise to very complicated propagation paths. In figure 4 a so-called "coverage diagram" is presented for an evaporation duct height of 20 m. The radar frequency is 16 GHz and the antenna is located at an altitude of 8 m and has an elevation of zero degrees. Note that the path loss is very large at altitudes of 3 to 4 m for all ranges except the very short distances. This means that a low flying missile can approach the platform without being detected when a frequency of 16 GHz has been chosen for surveillance under these circumstances. Obviously, when the radar operator has a Decision Tool available that informs him about the actual radar coverage, he will not stick to this frequency. More information about propagation can be obtained from [2,3,4].

Apart from the transmitter frequency of the radar, there are other radar parameters that have a significant influence on the detection probabilities. The pulse repetition frequency (PRF) of the radar introduces so-called blind ranges and blind velocities [5], as is illustrated in the "blind zone diagram" of figure 5.

Blind ranges occur because, at the moments the radar is transmitting a pulse, the reception of echoes from previous pulses is not possible. The time between two pulses is 1/PRF, in which PRF is the pulse repetition frequency, which is often in the order of kHz or tens of kHz. Therefore, for targets at distances that are integer multiples of c/(2×PRF), in which c is the speed of light, the possibility of detection is zero. In figure 5, the PRF is 5 kHz, and hence the blind ranges occur every 30 km.

Blind speeds occur because the clutter spectrum, which has a peak at a Doppler frequency of zero, repeats itself with a period equal to the pulse repetition frequency. As a consequence, when the Doppler frequency shift of a target is an integer multiple of the PRF, the target return has to compete with the ground clutter. Hence, when the target velocity is an integer multiple of $\lambda \times PRF/2$, in which λ is the wavelength, the possibility of detection is reduced. In figure 5, the wavelength is 0.03 m, and hence the first blind velocity occurs for a target velocity of 75 m/s.

In order to optimize the possibility of detection for a certain class of targets, it is obviously important to choose the PRF with care, or to vary the PRF regularly. The regular variation of the PRF is called staggering. The Decision Tool can assist the radar operator to make the right selection.

Apart from multipath, ducting, blind ranges, blind velocities, and clutter, also hostile jammers often pose a problem to the radar operator. The Decision Tool is able to predict the reduced detection probabilities in certain angular sectors when a jammer is present. This is illustrated in figure 6, where a scenario with three jammers has been chosen.

4. FUTURE DEVELOPMENTS

In the previous section, we have discussed a Decision Tool that informs the radar operator about detection probabilities,

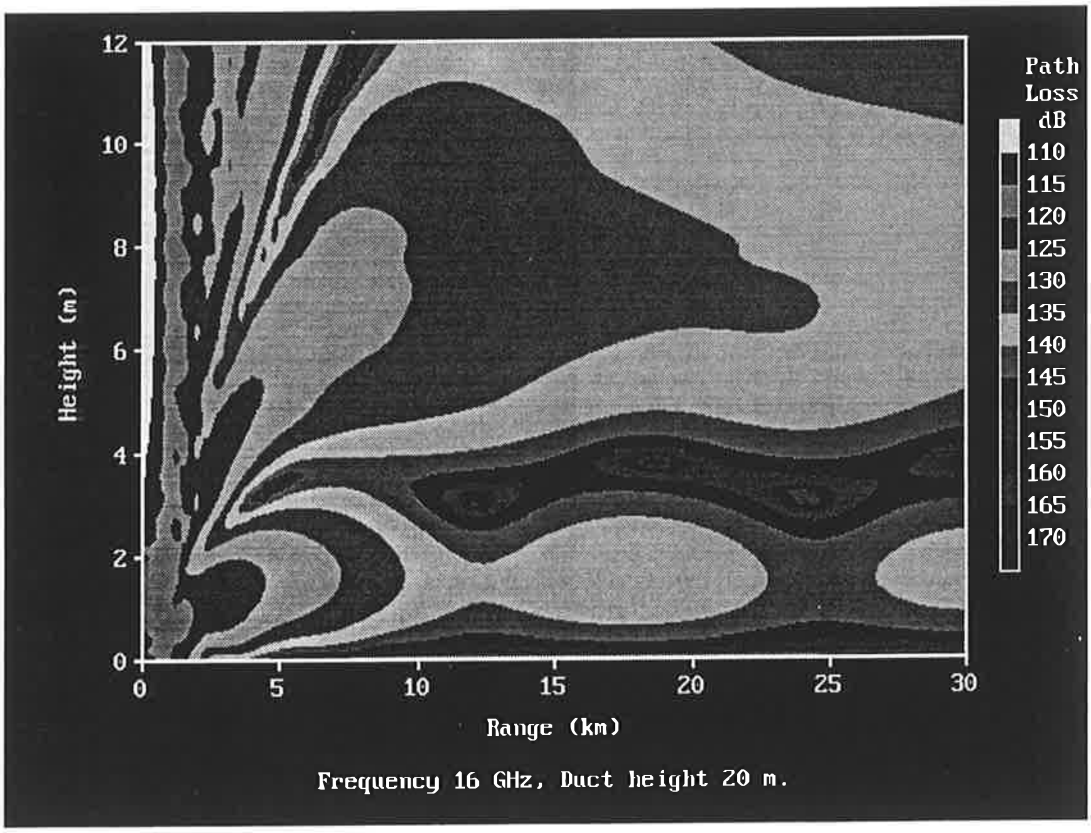


Fig. 4: Coverage diagram. Evaporation duct height 20 m, transmitter frequency 16 Ghz.

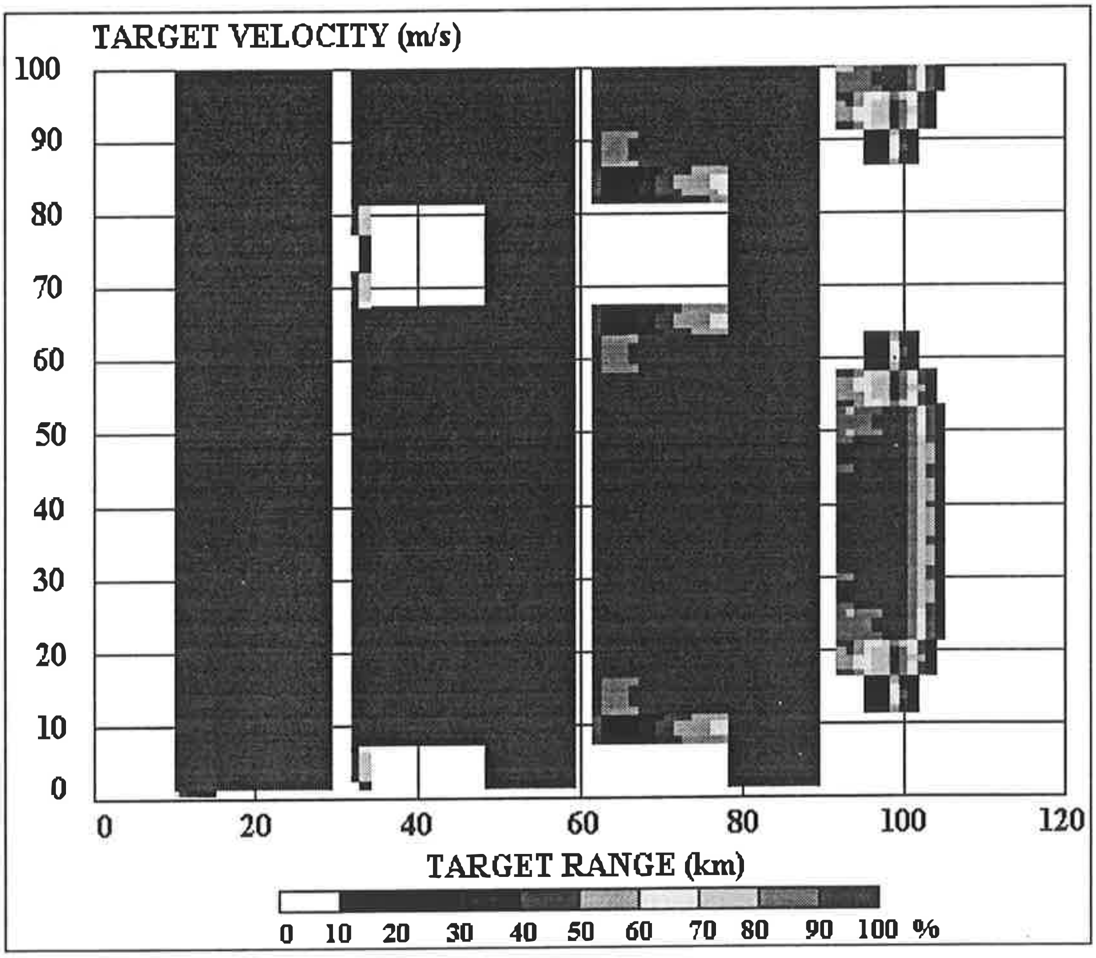


Fig. 5: Blind zone diagram. PRF = 5 kHz.

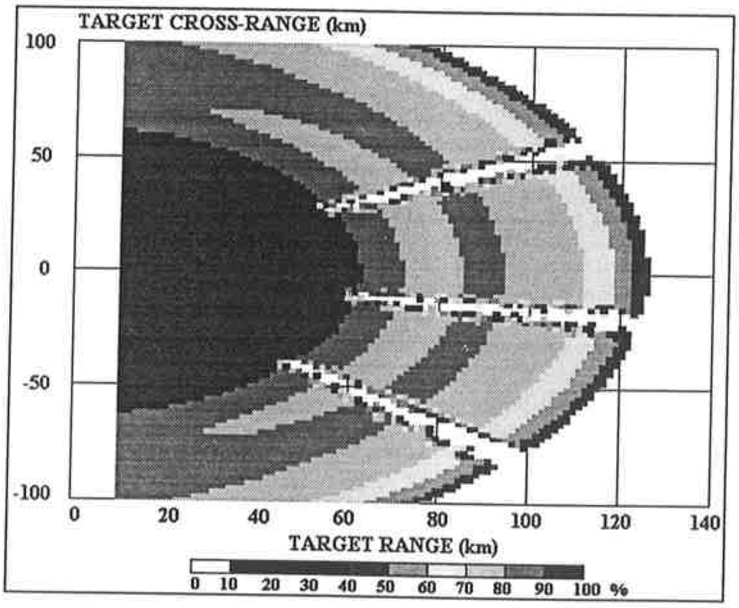


Fig. 6: Horizontal coverage diagram for a scenario with three jammers.

based on the selected radar parameters, the environmental conditions, the presence of jammers and the class of targets expected. When the operator wants to obtain the optimum radar parameters, he has to try out many possibilities. Often, he does not have the time for this. Therefore, we intend to modify the Decision Tool, in such a way that it is capable to <u>advise</u> the operator about which parameters to select, or, when applicable, to advise how to stagger several parameter values. As the Decision Tool is computationally intensive, parallel processing will be needed.

Further, it is our intention to increase the applicability of the Decision Tool. For instance, we wish to incorporate a more advanced propagation model in order to be able to calculate propagation over rough seas and over terrain with hills, cliffs and buildings. A possible model for this is given in [6]. Of course, in this case we will also need a more sophisticated clutter model to calculate the clutter returns from terrain. Another application for which we will need a more sophisticated clutter model is high-resolution radar. When radar pulses are very short, the clutter becomes very spiky, so that, for a certain average clutter level, false alarms can occur more often.

Last but not least, we wish to incorporate models for infrared systems in the Decision Tool, as infrared systems and radars can be complementary. An operational range prediction model for infrared search and track systems is presented in [7]. When the radar has a reduced coverage in a certain sector, because of the propagation conditions, the background clutter or jammers, the Decision Tool may advise to rely more on an infrared system in this sector. On the other hand, when the infrared system has a reduced coverage in a certain sector because of background radiation or aerosols, the Decision Tool can advise to rely more on the radar in this sector. For an optimum use of the time budget of the search systems, the Decision Tool can allocate certain sectors of the search volume to the radar and other sectors to the infrared system.

5. CONCLUSION

We have presented a Decision Tool that assists radar operators to select the optimum radar parameters for air defence, given the radar systems available, the environmental conditions and the class of targets that is expected. Some future developments have been discussed. The Decision Tool is expected to be a very powerful aid for both radar operators and commanders, and is expected to increase platform survivability.

6. REFERENCES

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