Simulation Methods for Prioritizing Tasks and Sectors of Surveillance in Phased Array Radars

S.L.C.Miranda, C.J.Baker, K Woodbridge, H.D.Griffiths

Department of Electronic and Electrical Engineering
University College London, Torrington Place, London, WC1E 7JE, United Kingdom.

s.miranda@ee.ucl.ac.uk , c.baker@ee.ucl.ac.uk , k.woodbridge@ee.ucl.ac.uk, h.griffiths@ee.ucl.ac.uk

Abstract - **Multifunction phased array radars have the ability to steer the radar beam electronically, adapting its parameters according to how the radar perceives the environment. Thus, the effective allocation of the available resources is very important. A model of a multifunction phased array radar was implemented to examine the complexities involving this type of radar. Additionally, approaches to adaptively assigning priorities of targets and sectors of surveillance are developed and assessed. Ranking radar tasks is an important sub-problem for radar resource management. When the radar resources are not sufficient to undertake all its functions, their priorities will indicate an appropriate manner of reallocating the radar resources. In this paper, simulation methods to evaluate prioritization of tasks are described.**

Keywords - radar simulation, multifunction radar, priority assignment.

I. INTRODUCTION

Phased array antennas have matured rapidly in recent years and this technology is set to become the norm in complex and advanced radar systems. The ability to steer the radar beam electronically is highly desirable as the reaction time is faster than in traditional mechanically steering radars. This allows the combination of functions, such as tracking, surveillance and weapon guidance, which were traditionally performed by dedicated individual radars. This new type of radar is called multifunction radar.

A phased array multifunction radar has a high degree of adaptability and is able to adapt beams as a result of knowledge acquired from the scene under interrogation. This knowledge has a high level of uncertainty, and hence we have a poorly posed problem for a control loop that contains many variables. This leads to a challenging simulation problem. For example, having many tasks to perform, the multifunction radar has to make a decision as to which functions are to be performed first or which must be degraded or even not done at all when there are not enough resources to be allocated. The process of making these decisions and determining their allocation as a function of time is known as radar resource management (RRM).

In this paper, we present simulation methods that were used to analyse and understand the radar resource management issue in naval applications. In particular, we develop a multifunction phased array radar model and examine adaptive priority assignment methods to fixed task priority schemes in changing tactical scenarios. In radar resource managers, a prioritisation module will have a close relationship with the scheduling function. This scheduling function has to consider a number of constraints such as time and energy in order to maximise the number of the tasks that are able to meet their desired deadline. Ranking radar tasks is an important sub-problem for radar resource management. It not only contributes to an efficient scheduling process by defining which conflicting tasks are going to be delayed, but also influences the overall resource allocation by determining the tasks that will not be performed in stressing conditions.

Although functional simulations of multifunction radar systems involving scheduling and task ranking may give some insights of their overall effects on resource allocation and radar system performance, just a few reports have addressed this subject [Orman et. Al, 1998; Watson, 2002]. However, there have been a number of reports in the literature examining resource management from the perspective of the design of efficient scheduling algorithms, using neural network, Operations Research (OR) theory and related techniques [Izquierdo-Fuente and Casar-Corredera, 1994; Strömberg and Grahn, 1996; Orman et al., 1996]. In addition, few reports have analysed target ranking by using either neural network or fuzzy logic. These have the advantage of making softer or slower decisions and hence not re-assigning resources instantly if not absolutely required [Molina Lopez et al., 1998; Komorniczak et al., 2000, 2002; Vine, 2001].

This paper is organized as follows. Initially, section 2 describes the architecture of the simulation used in the analysis. Next, section 3 presents the earlier implementations of the radar model and some results of a comparison of two scheduling algorithms described in the literature. In section 4, methods of prioritising tracking and surveillance tasks are examined by the use of fuzzy logic techniques. The preliminary results of this examination are presented in section 5, and section 6 gives some concluding comments.

II. DESCRIPTION OF THE SIMULATION ARCHITECTURE

Considering that there are several possible approaches to address radar resource management, a simulation model of a multifunction phased array radar was developed to provide a better understanding of their effects on the final allocation of the radar resources and on the radar performance.

The present work considered the behaviour of one face of a multi-face phased array antenna radar system. For simplification, the study included both radar functions of surveillance and tracking.

The architecture used in the radar model is presented in figure 1. It provides an environment in which different radar resource management techniques could be represented and examined against any given operational scenario. The radar model was developed using MATLAB. A modular approach was used in developing the simulation model. The advantage of this modularity was that comparisons of different techniques could be performed keeping fixed other radar parameters. Furthermore, the approaches were compared under the same initial conditions and the same tactical characteristics in respect to targets and environment.

This aspect is particularly useful when analyzing ill-defined problems, such as RRM. It is possible to achieve a better understanding of the sensitivities of the parameters involved according to the approaches under study.

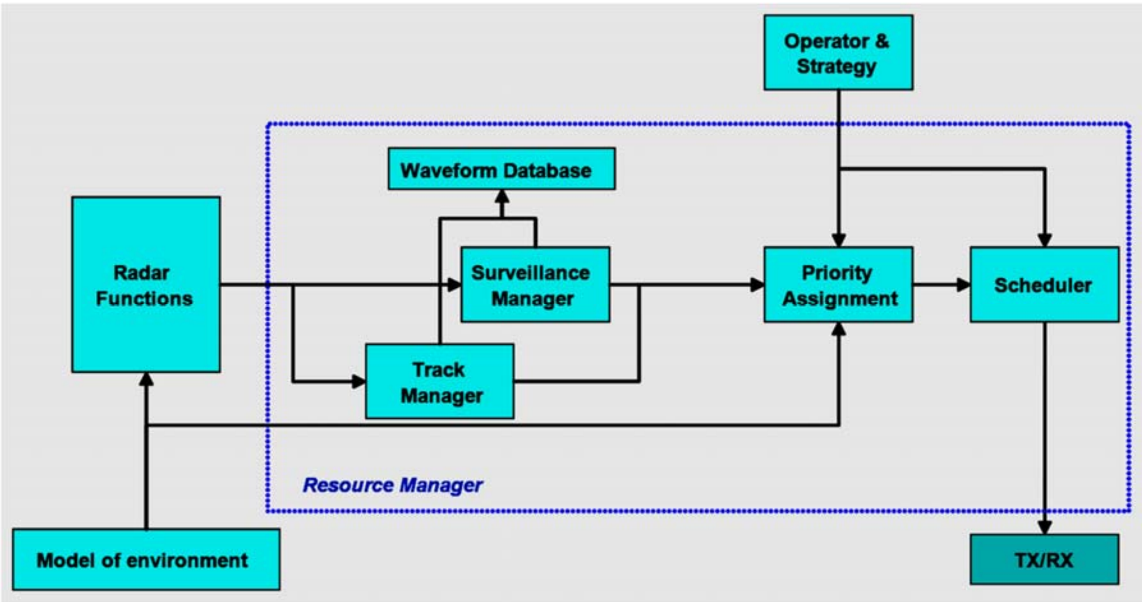

Figure 1. Block diagram of the simulation architecture used in the comparison

The main blocks are briefly described here:

A. Scheduler

The scheduling algorithm is responsible for effectively assigning a set of measurement tasks to the multifunction radar considering resource constraints, such as time and energy. It should create a list of tasks to be performed by the radar, maximizing the number of tasks that meet their deadlines.

B. Priority Assignment

This block assigns degrees of importance for the tasks that must be executed by the radar. Several factors may be taken into consideration when evaluating the task priority, such as evolution of the environment, the nature of the task (surveillance, tracking, and weapon guidance), degree of threat of the target under track, etc.

C. Surveillance Manager

This function maintains a queue of unscheduled surveillance tasks and provides the scheduler with a smaller list of requests that are close to the execution time. It also selects the parameters of the waveform to be used in the transmission of the radar pulses, meeting the requirements of surveillance performance.

D. Track Manager

Similar to the surveillance manager, it keeps a list of unscheduled track requests, sending them to the scheduler when appropriate. The track requests are generated by the tracking process associated to each target, which determines the next desired update time and the position of the radar beam for the measurement in order to achieve the requirements of tracking performance.

F. Radar Functions

Two radar functions are represented in this case of study. Firstly, the surveillance function is responsible to create a list of task requests that correspond to radar beam positions that must be looked at in order to maintain a required detection performance over a radar coverage area. Lastly, the tracking function represents the filters used for keeping known the actual and future positions of detected targets. In this work, an adaptive Kalman filter was used.

F. Operator and Strategy

Accounts for the overall preferences related to the radar mission and to decisions made based upon evaluation of the tactical scenario.

III. EARLIER IMPLEMENTATIONS

The radar model developed in this work was already applied to address the comparison of different scheduling approaches described in the literature [Miranda et. al]. The algorithms are presented in [Orman et al., 1996; Butler, 1998]. Both algorithms were codified and used in the simulation architecture presented in figure 1. Several load situations were considered to allow the evaluation of their behaviour under different environments, when there may exist or not enough radar resources to maintain the required performance for all radar jobs.

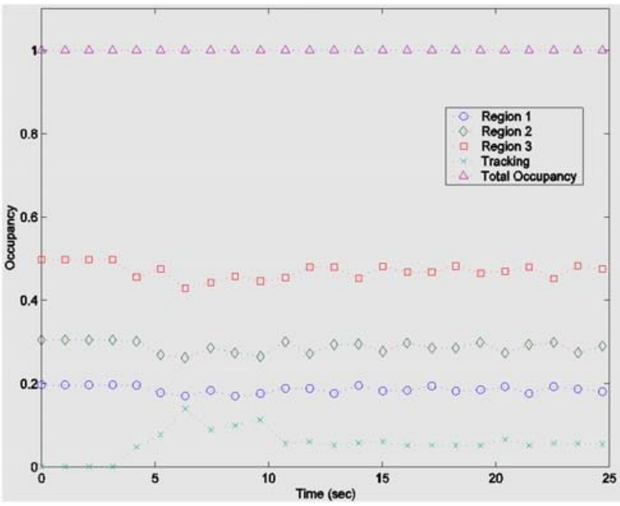

Figure 1. Radar load resulting from the use of the Butler type scheduling algorithm

The results indicated that although very different in implementation, the scheduling algorithms showed broadly similar performance in respect to the ability of both planning the radar task timeline and scheduling tasks as close as possible of their due time of execution.

The analysis was done under the same test conditions for both algorithms.

Figure 2 shows the results of a simulation in which the radar coverage was divided into three sectors of surveillance.

Initially, it was considered that no target was detected. Thus, only surveillance tasks were performed and the radar load in each sector was determined by the required detection performance. After a few seconds, several targets are progressively detected and, as target tracking was considered more important than surveillance, the detection performance is gradually degraded.

Figure 3 shows the performance of the same algorithm when planning the execution of tracking tasks.

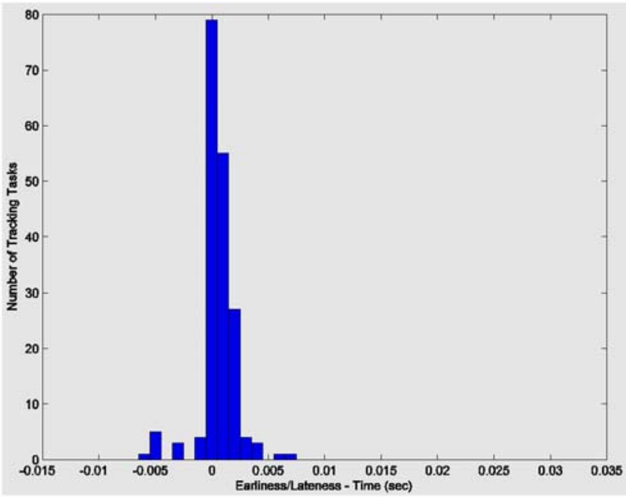

Figure 2 . Number of Tracking Tasks x Earliness/Lateness when using the Butler type scheduler

In order to better use the radar timeline, some tasks were scheduled either earlier or later than their due time. However, this effect was not relevant in respect to the performance of the tracking function.

IV. PRIORITIZING RADAR TASKS

Examination of the results from the previous comparison suggested that an important method to investigate radar resource management was to develop an adaptive prioritization assignment for both targets under track and sectors of surveillance.

The idea was to use information provided by other sensors that usually coexist in a platform using multifunction radars to come to a more accurate conclusion about the importance of a given radar function. For example, the identity of a target can be inferred by using an IFF system or even the multifunction radar itself operating in high resolution mode. It is reasonable to consider that, in some situations, less radar resources should be spent tracking friendly targets at high range than looking for new targets in a surveillance sector where an increasing number of threatening targets is being detected. Thus, as the tactical environment evolves, the priorities should be adaptively reassigned to the radar tasks, resulting in a continuous reallocation of the radar resources.

Two different methodologies were examined here. These fuzzy reasoning priority assignment approaches therefore were based upon the two decision trees presented in figures 4 and 5.

A. Prioritizing Tracking Tasks

The priority of tracking targets (fig. 4) was evaluated according to information provided by the tracking algorithm and by other sensors or other operation modes of the multifunction radar, for example a high resolution mode.

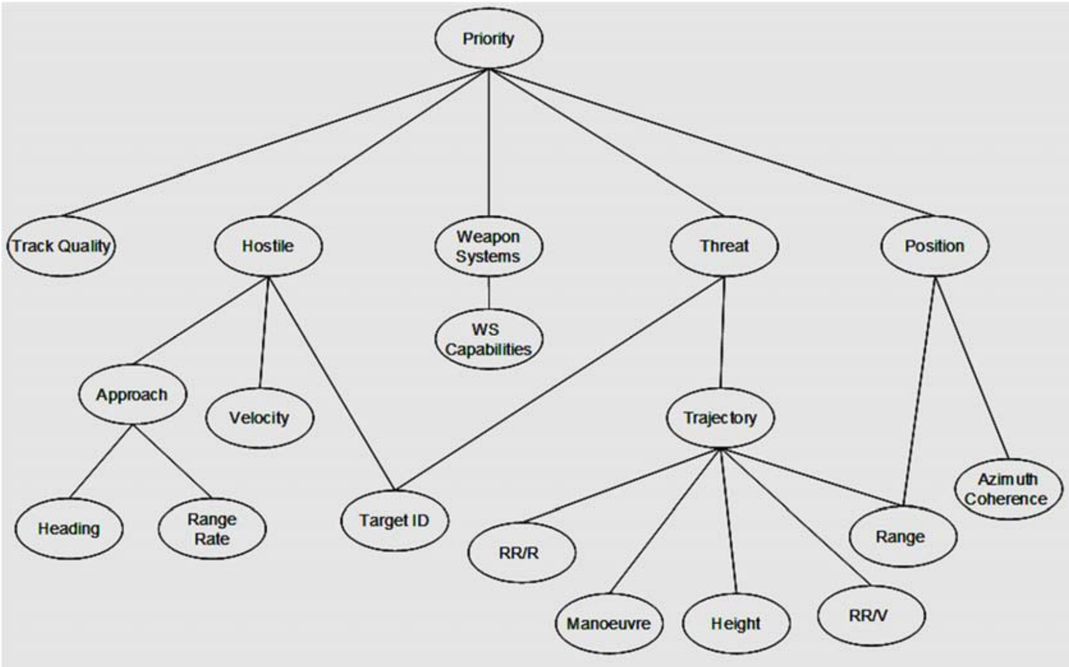

Figure 3: Decision tree for targets priority assessment

Five different variables provided information concerning the degree of threat, hostility, and weapon system capabilities of the platform, quality of tracking and relative position of the target. Fuzzy values were attributed to each variable. Some examples of the fuzzy values are presented in table I. After evaluation of these variables according to a set of fuzzy rules, the importance (priority) of the target was determined.

TABLE I. EXAMPLES OF FUZZY VARIABLES USED IN THE ASSIGNMENT OF PRIORITIES FOR TARGETS

Fuzzy Variable	Fuzzy Values
Priority	Very low, Low, Medium Low, Medium, Medium High, High, Very High
Hostile	Non-hostile, Unknown and Hostile
Weapons Systems	Low, Medium and High priorities
Threat	Very Low, Low, Medium Low, Medium, Medium High, High and Very High
Position	Close, Far, Medium

A similar methodology was applied to the surveillance function. In this case, the priority of surveillance sectors (regions) was assessed through the original priorities attributed to the regions with respect to the expected tactical scenarios and the information gathered during the evolution of the actual environments, see figure 5.

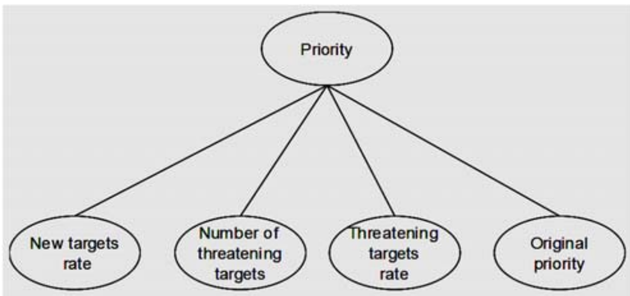

Figure 4. Decision tree for sectors of surveillance priority assessment

This included aspects such as rate of new targets, number of threatening targets and rate of new threatening targets. A set of fuzzy rules enabled the evaluation of the priority of the different sectors considered for surveillance.

V. RESULTS

Initial simulation results are showed in figures 6 and 7. The aim is to evaluate the effects in resource allocation and radar performance, when using both fixed priority assignment systems and the fuzzy reasoning priority approach developed in this work.

Figure 6 presents the priority evolution of aircraft moving along the same trajectories with different degrees of threat level. It is shown that the higher the degree of threat of a target, the greater its priority will be. This aspect is particularly important in stressing situations where there are not sufficient resources to perform all the requested tasks and the resource manager must decide which of the radar functions will be degraded.

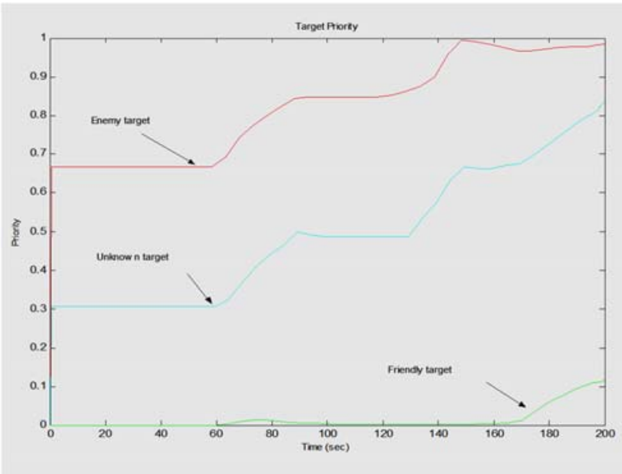

Figure 5. Priority evolution of targets with different threat degrees, moving along the same trajectory

In addition, figure 7 shows the adaptive prioritization of a sector of surveillance when using the fuzzy approach proposed in section 3.2.

At first, it was considered that there were no detected targets in the sector under observation. Gradually, targets moved into the sector and were detected. Subsequently, their degrees of threat were evaluated according to the method presented in figure 4. The combination of the original priority of the sector with the number of threatening targets and total number of targets detected in the sector provided an evaluation of the importance of the surveillance tasks in that sector.

TABLE II. RADAR TASKS RANKING ORDER

Priority	Radar Task
1	Track maintenance
2	Plot confirmation
3	Track initiation
4	Track update
5	Surveillance
6	Auxiliary tasks

In the fixed task priority scheme, the original task ranking will not evolve even though the environment is changing. In the analysis presented here, the priority order in table II was used as reference. Figure 8 shows the results of the simulation of an overload situation using this priority order.

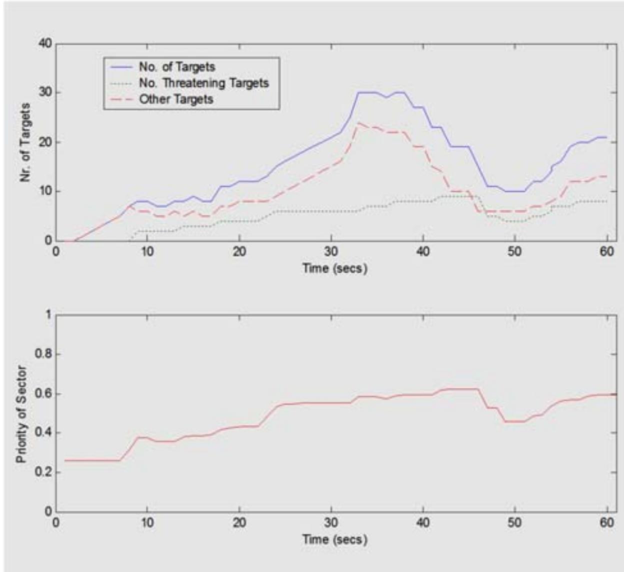

Figure 6: Evolution of the priority of a surveillance sector when the tactical scenario is varying over time.

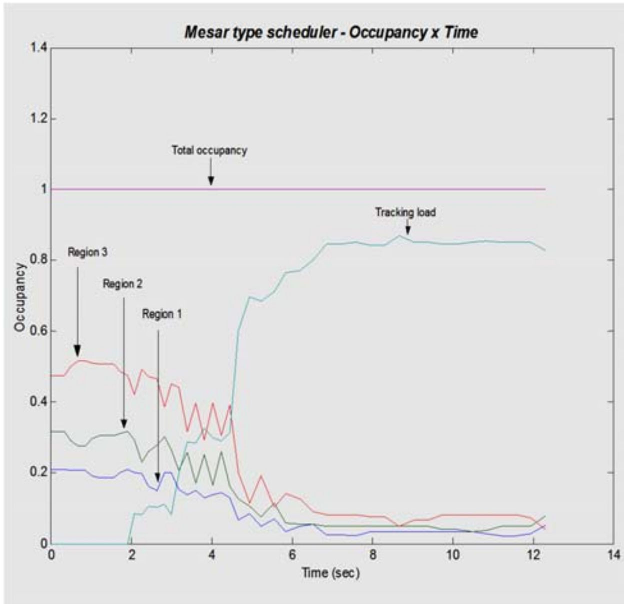

Figure 7: Results form the simulation of an overload situation using a fixed priority scheme in which tracking tasks prevail over surveillance tasks.

We considered a region of coverage spanning from -45º to +45º away from the antenna's broadside and divided this into three different sectors. As the amount of available radar resources was extinguished, the performance of lower priority functions was degraded to the point that no surveillance performance at all was achieved in some sectors.

VI. CONCLUSION

In this paper, we have described a viable simulation strategy that copes with an ill-defined control loop problem, where many variables are present. This has been achieved by making a number of simplifications in the representation of the environment as seen by the radar. This has then allowed a comparison of different resource management techniques.

The functional simulation of a multifunction radar presented here helps to provide important insights in the resource management issue. It proved useful when analyzing the performance of different scheduling algorithms. Although diverse techniques were used in the design of the algorithms, the results showed that their overall performance was broadly similar.

A similar analysis is to be done considering the priority assignment approaches presented in this work. The initial results suggest that the fuzzy approximation is valid to evaluate the importance of targets and sectors of surveillance. By assessing the priorities according to a set of rules that imitates the human decision-making process in a similar tactical situation, the resource manager can distribute the radar resources in a more effective way.

REFERENCES

[1] Billetter, D. R.: “Multifunction Array Radar”, Artech House, 1989.

[2] Butler, J. M.: “Multi-Function Radar Tracking and Control”, University College London, PhD Thesis, 1998.

[3] Izquierdo-Fuente, A.; Casar-Corredera, J.R.; “Optimal radar pulse scheduling using a neural network”. In IEEE International Conference on Neural Networks, Orlando, USA, 1994. Pp 4588 - 4591 vol.7

[4] Komorniczak, W.; Kuczerski, T.; Pietrasinski, J.F.; “The Priority Assignment for Detected Targets in Multi-function Radar”. In 13th International Conference on Microwaves, Radar and Wireless Communications, Wroclaw, Poland, 2000. Pp 244-247. Vol.1.

[5] Komorniczak, W.; Pietrasinski, J.; Solaiman,B.: “The Data Fusion Approach to the Priority Assignment in the Multifunction Radar”. In 14th International Conference on Microwaves, Radar and Wireless Communications, Poland, 2002. Pp 647-650. Vol. 2.

[6] Miranda, S.L.C.; Baker, C.J., Woodbridge, K. and Griffiths, H.D.; “Phased Array Radar Resource Management: A Comparison of Scheduling Algorithms”, unpublished.

[7] Molina Lopez, J.M.; Jimenez Rodriguez, F.J.; Casar Corredera, J.R.; “Fuzzy management of surveillance sensors”. In 37th IEEE Conference on Decision and Control, Tampa, USA, 1998. Pp 245 - 250 vol.1

[8] Orman, A.J. , Potts, C.N., Shahani, A.K. & Moore, A.R.: “Scheduling for a Multifunction Array Radar System”. In European Journal of Operational Research, Vol. 90, 1996.

[9] Orman, A.J., Shahani, A.K. and Moore, A.R.: “Modelling for the Control of a Complex Radar System”. In Computers and Operations Research, Vol. 25, No. 3, 1998. Pp. 239-249.

[10] Strömberg D.; Grahn P.: “Scheduling of Tasks in Phased Array Radar”. In IEEE International Symposium on Phased Array Systems and Technology, Boston, USA, 1996. Pp 318 – 321.

[11] Vine, M. T.: “Fuzzy Logic in Radar Resource Management”. In IEE Multifunction Radar and Sonar Sensor Management Techniques (Ref. No. 2001/173), 2001. Pp 5/1 - 5/4.

[12] Watson, R.; “Radar resource management modelling”. In Proc. RADAR 2002, Edinburgh, Scotland, 2002. Pp 562-566.