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SIMULATION MODEL OF LOGISTIC SUPPORT TO ISOLATED AIRSPACE SURVEILLANCE RADAR STATIONS

ABSTRACT

A simulation model of the radar network operation of five military radar stations has been developed. Simulation was performed in GPSS language and contains the time of operation of five radars through a period of one year, time of planned preventive maintenance, irregularities, time of corrective maintenance and maintenance team(s). The simulation shows the influence of the number of maintenance teams on the availability of each radar and presents a good orienteering point for defining the optimal model of preventive and corrective maintenance of the radar network.

KEY WORDS

radar, team, maintenance, discreet events, GPSS

1. INTRODUCTION

The distribution of units for airspace surveillance of the entire territory of the Republic of Croatia represents a big challenge for the logistics support and complicates the model of radar system serving. How and in which way should the defined, i. e. required availability of the entire system be organized, and how to organize and which serving model to use – these are the issues which affect the success of performing the basic task of the very system, which is – surveillance of the Croatian airspace [4].

The installation of new Lockheed Martin FPS-117 radar systems for the surveillance of the Croatian airspace requires reorganization of the past model of preventive and corrective maintenance. Until now, the radar network maintenance model was, namely, adapted to older generation radars and assumed the presence of the maintenance unit at the radar position, i. e. at the radar the whole time of its operation. The considerations in this paper start from the assumption that, regarding the new radar manufacturer's data [10], as well as regarding the field data, it is possible to define the serving model with one central warehouse and a certain number of mobile maintenance teams.

The assumption in the simulation model, namely, is that mobile team(s) for preventive and corrective maintenance are not located at the location of the very radar but rather form a part of the Serving Centre (central warehouse) and go to a certain radar position when there is need for it (preventive or corrective), serve the radar and return back. The results of the simulation show the number and duration of irregularities at certain radars during a period of one year regarding the available number of maintenance teams, the number and duration of radar "waiting" for the maintenance team and the availability of the radar regarding the number of teams.

2. RADAR MAINTENANCE

The predicted airspace surveillance radar operation in peacetime conditions is 24/7 which means 24 hours a day, seven days a week. The radar does not operate or is turned off from operative operation in case of preventive or corrective maintenance. It is turned off in case of immediate danger from air, but this, as well as the possibility of radar destruction in case of war has not been presented by the simulation.

Preventive maintenance is planned maintenance and it is planned for a certain time period. The frequency of inspections and maintenance works and the respective procedures are set by the radar manufacturer. After a certain period of radar usage the user redefines the method and time necessary to serve the radar and adapts it to their own needs and requirements, all with the purpose of fewest possible interventions through corrective maintenance.

Corrective maintenance refers to failure or malfunction of a part of the radar, its identification, diagnosis, repair and control. In practice corrective maintenance is reduced, in the majority of cases (and thus described also in the model) to replacement of the malfunctioning module which later, depending on the defect and construction is either repaired or written off.

The simulation model considers the operation of the system in its useful life-cycle (which follows after early failure, the so-called "teething problems", and precedes the period of obsoleteness and wear-out) and the failure intensity (λ) is considered a constant [1,6].

3. DESCRIPTION OF THE MODEL

In the model the radars have been presented as serving request generators [3,7]. The radar, namely, generates request for preventive maintenance (planned) or generates request for corrective maintenance (possible failures, i. e. breakdowns).

3.1 Scheme of the model

The scheme of the maintenance model is presented in Figure 1.

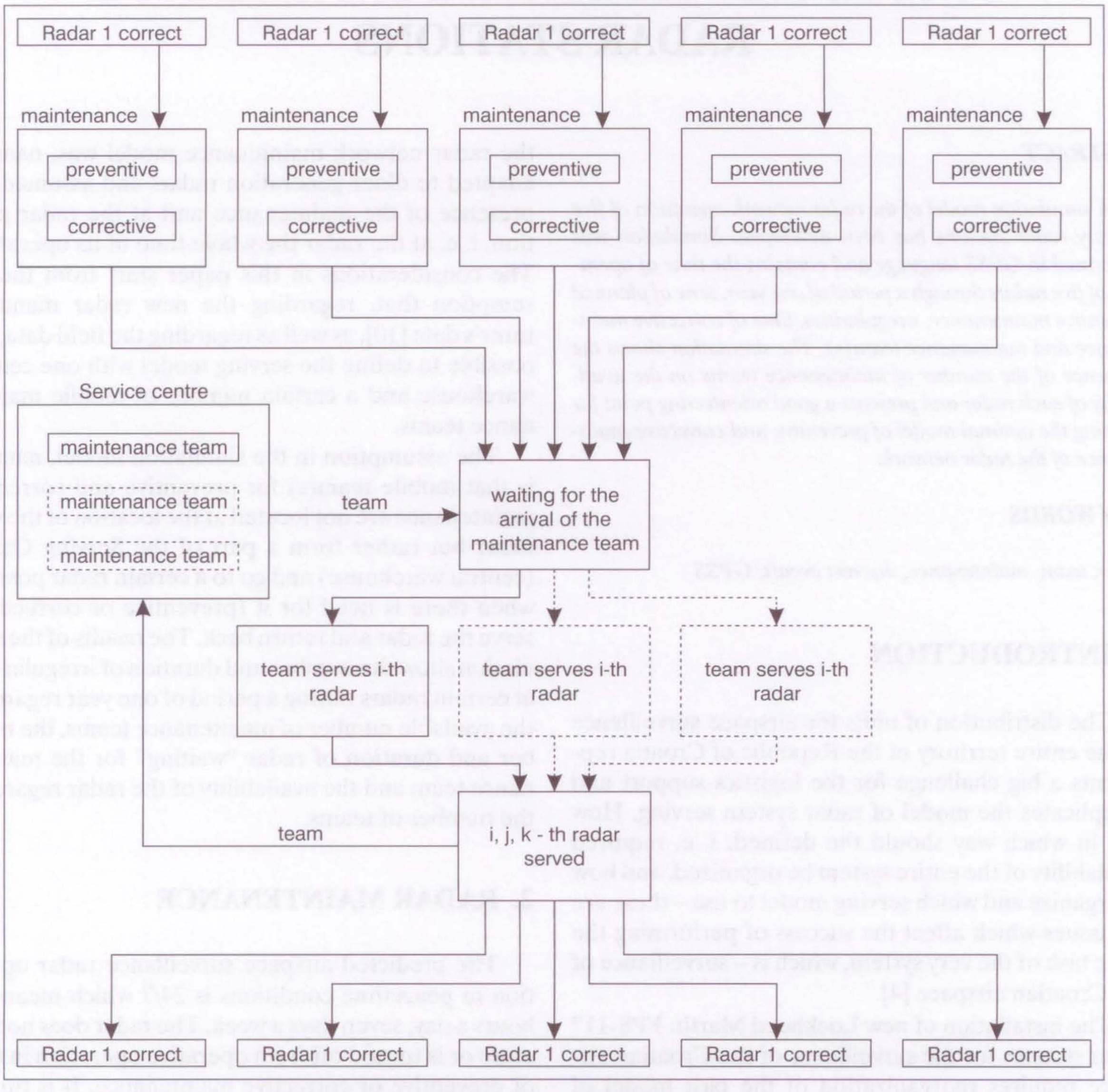


Figure 1 – Maintenance model scheme

3.2 Preventive maintenance

Preventive maintenance in simulation is planned once a month. Apart from monthly generation of the request for prevention, the radar generates also a three-monthly, half-yearly and yearly request, but only once a month (three-monthly inspection is at the same time a monthly inspection, half-yearly is also three-monthly and monthly, and yearly is at the same time half-yearly, three-monthly and monthly preventive inspection). Of course, they differ in duration; the monthly inspection is the shortest, and the annual one the longest. Since the operation of five radars over a period of one year is simulated, there are 60 generations of requests to engage the maintenance team for the entire radar network (12 requests per radar).

Preventive maintenance is planned activity over a longer period of time and there should be (and there is) no overlapping of the requests for engaging the teams for preventive maintenance. Deviation from the set schedule is only time-postponement of the inspection before or after the planned schedule, and the very inspections and preventive maintenance procedures take approximately the same (the departure from the schedule may result e. g. from a military exercise in the airspace that is best covered by the respective radar, etc.).

3.3 Corrective maintenance

Radar malfunction generations and their corrective maintenance have been determined by the manufacturer's data, i. e. the mean time between failure (MTBF). The time between failures is assumed by the exponential distribution (number of malfunctions is a constant in time), and the very engagement of the team serving the radar is given according to the manufacturer's data (MTTR - *Mean Time to Repair*) and normal distribution [2,10].

3.4 Team engagement

The travel duration of the team from the Serving centre to the radar location and back has been assumed by normal distribution. The radar, namely, at a certain time period generates the request for engagement of the team (preventive – planned or corrective – predicted malfunction) and the team, if free and available, starts from the Serving centre, serves the radar and returns back. This means that in case of preventive request of the radar, its malfunction is only within the operation time of the team on the radar. Since single preventive inspections take even several days, the simulation has assumed that during the time the team takes a rest (in the afternoon and at night at the radar location) the radar is again in the status "correct" and available for possible use.

Also in case of generating a corrective request of the radar (malfunction) the team starts from the Serving centre and, in this case, brings the radar into proper functioning status by replacing the malfunctioning module. During radar downtime, of course, apart from the time of working on the radar the calculation needs to include also the time necessary for the team to arrive from the Serving centre.

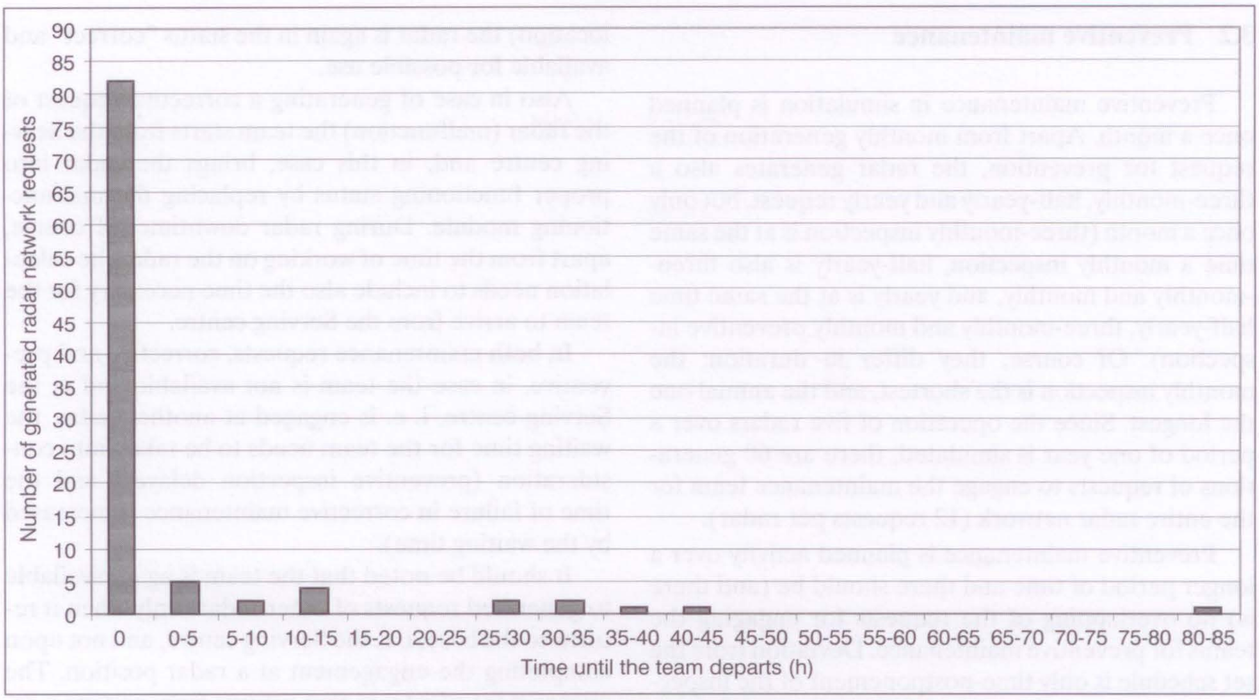
In both maintenance requests, corrective and preventive, in case the team is not available and at the Serving centre, i. e. is engaged at another radar, the waiting time for the team needs to be taken into consideration (preventive inspection delayed, and the time of failure in corrective maintenance is increased by the waiting time).

It should be noted that the team is again available to generated requests of other radars only when it returns to the base, i. e. the Serving centre, and not upon completing the engagement at a radar position. The engagement of a team that returns from serving a radar does not influence any more the proper functioning of the radar from which it is returning (this one being served and operating, but influencing the other four since the team has to return to the Serving centre and take spare parts and tools for the next task). It is logical that the team is equipped for each individual radar and its needs of monthly, three-monthly, half-yearly or annual preventive i. e. corrective maintenance. It may happen, however, that after serving one radar the team does not return to the Serving centre but rather proceeds to the next radar and serves it (the team is rested, has the tools and the necessary spare parts), but this has not been planned in the simulation.

4. SIMULATION

This simulation modelling of the radar operation uses the GPSS (*General Purpose Simulation System*) simulation language [5,8]. After designing the simulation model and having input the number of radars, the parameters of preventive and corrective maintenance, the travel times of the team(s) to the radar and back, the serving model with one, two or three teams has been simulated.

The model shows that within a period of one year five radars generated a total of 100 requests for team engagement. Graph 1 shows that in case of one team, there was no waiting in 82 cases (being at the Serving centre and available and immediately departed to the radar that generated the request). Furthermore, five times up to five hours were needed for the team to depart, two times between five and ten hours, four times between 15 and 20 hours, etc., and in one case even over 80 hours.



Graph 1 – Number and time of waiting for a team

In case of two teams being engaged in the simulation model out of 100 requests to engage the teams at least one team was at the Serving centre ready to be engaged. There is no waiting, the team starts immediately to the radar which generated the maintenance request (preventive or corrective) whereas the other team was either at the Serving centre or serving another radar (or under way).

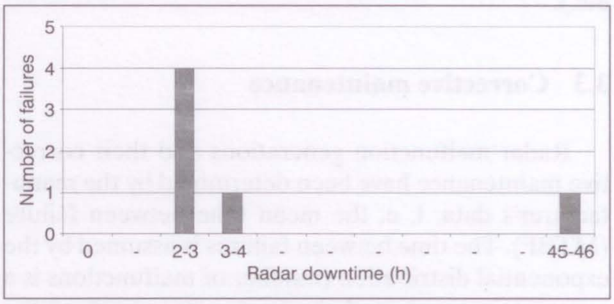
The introduction of the third team in the simulation model has resulted in no change regarding waiting. The maximum of "non-waiting" of all the requests has been reached in the case of two teams so that the result with three engaged teams has been expected.

5. RADAR DOWNTIME

The radar downtime, i. e. time during which the radar was not operating differs regarding the method in which the downtime was caused. In case of preventive maintenance, it is planned and predicts monthly (three-monthly, half-yearly and yearly) radar downtimes. This was also planned by the simulation.

Apart from generating requests for preventive maintenance the radar generates also the request for corrective maintenance. It is planned for every radar on the average every 1000 hours (MTBF), but one does not know exactly when this is going to happen.

Radar generates the request for corrective maintenance i. e. failure and from that moment the downtime starts to be measured. The downtime contains the waiting time for the team (if not at Serving centre), travelling time of the team from the Serving centre to the radar and radar repair. Graph 2 shows the Radar 1 downtime (corrective defect, in case of failure) if network of five radars is served by one team.

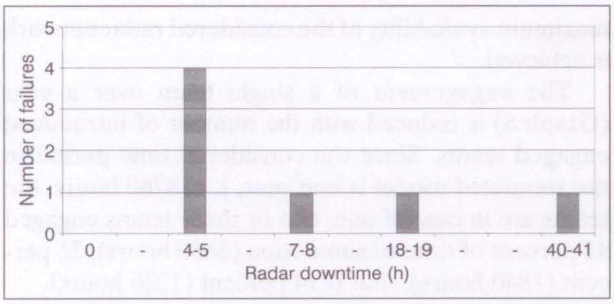


Graph 2 – Number and duration of Radar 1 downtime in case of one team

It may be seen that Radar 1 (Graph 2) generated six downtimes in one year. Four downtimes take between two and three hours, and the other two downtimes took between three and four hours, and 45 and 46 hours, respectively.

By introducing the second team into the simulated model the Radar 1 downtimes over a period of one year are reduced (of course, the same number of downtimes remains – this is something that cannot be affected by the number of teams, but are shorter). All the six downtimes take between two and three hours.

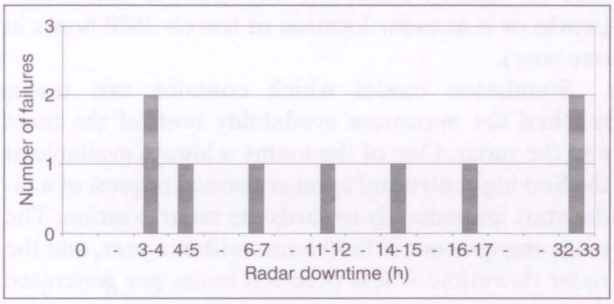
Radar 2 (Graph 3) generated seven downtimes over a year. In case of one team four downtimes take between four and five hours, and the remaining three take between seven and eight hours, between 18 and 19 hours and between 40 and 41 hours, respectively.



Graph 3 – Number and duration of Radar 2 downtime in case of one team

By introducing the second team into the simulated model the Radar 2 downtime is reduced; all seven downtimes take between four and five hours.

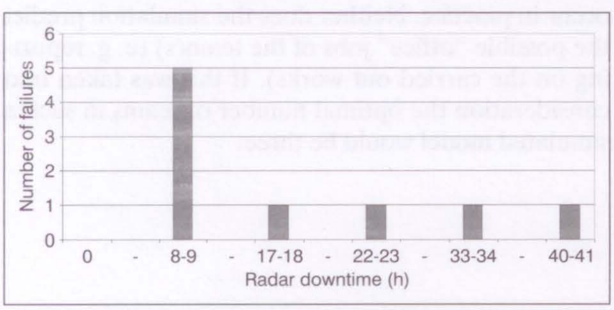
Radar 3 (Graph 4) generated nine downtimes in one year. In case of one team two downtimes take between three and four hours and two take between 32 and 33 hours, and the rest take between four and five hours, six and seven hours, 11 and 12 hours, and between 16 and 17 hours, respectively.



Graph 4 – Number and duration of Radar 3 downtime in case of one team

By introducing the second team in the simulated model the Radar 3 downtime is reduced; six downtimes take between three and four hours.

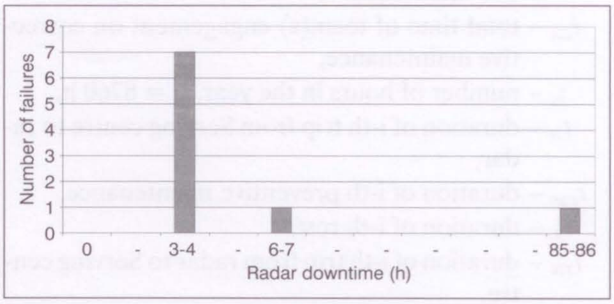
Radar 4 (Graph 5) generated nine downtimes over a period of one year. In case of one team five downtimes take between eight and nine hours, and each of the remaining four take between 17 and 18 hours, 22 and 23 hours, between 33 and 34 hours, and between 40 and 41 hours, respectively.



Graph 5 – Number and duration of Radar 4 downtime in case of one team

By introducing the second team into the simulated model Radar 4 downtime is reduced; all nine downtimes take between eight and nine hours.

Radar 5 (Graph 6) generated nine downtimes over a year. In case of one team seven downtimes take between three and four hours, and each of the remaining two take between six and seven hours and between 85 and 86 hours, respectively.



Graph 6 – Number and duration of Radar 5 downtime in case of one team

By introducing the second team into the simulated model Radar 5 downtime is reduced; all nine downtimes take between three and four hours.

6. AVAILABILITY AND ENGAGEMENT

The availability is calculated according to the following expressions:

$$A = \frac{t_u - (t_{PM} + t_{CM})}{t_u},$$

$$t_{PM} = \sum_{i=1}^{n} t_{PMi},$$

$$t_{CM} = \sum_{i=1}^{m} t_{Wi} + \sum_{i=1}^{m} t_{Ti} + \sum_{i=1}^{m} t_{CMi},$$

where:

t_u – number of hours within a year, $t_u = 8760$ h,

t_{PM} – total time of preventive maintenance,

t_{CM} – total time of corrective maintenance,

n – number of preventive inspections during a year (n=12),

t_{PMi} – duration of i-th preventive maintenance,

m – number of corrective maintenance within a year,

t_{Wi} – duration of i-th waiting for the team arrival,

t_{Ti} – duration of i-th trip from the Serving centre to the radar,

t_{CMi} – duration of i-th corrective maintenance.

The engagement of teams is calculated according to the following expressions:

$$E = \frac{t_{PA} + t_{CA}}{t_u},$$

$$t_{PA} = \sum_{i=1}^{n} t_{Ti} + \sum_{i=1}^{n} t_{PMi} + \sum_{i=1}^{n} t_{Ri} + \sum_{i=1}^{n} t_{TBi},$$

$$t_{CA} = \sum_{i=1}^{m} t_{Ti} + \sum_{i=1}^{m} t_{CMi} + \sum_{i=1}^{m} t_{TBi},$$

where:

t_{PA} – total time of team(s) engagement on preventive maintenance,

t_{CA} – total time of team(s) engagement on corrective maintenance,

t_u – number of hours in the year, $t_u = 8760$ h,

t_{Ti} – duration of i-th trip from Serving centre to radar,

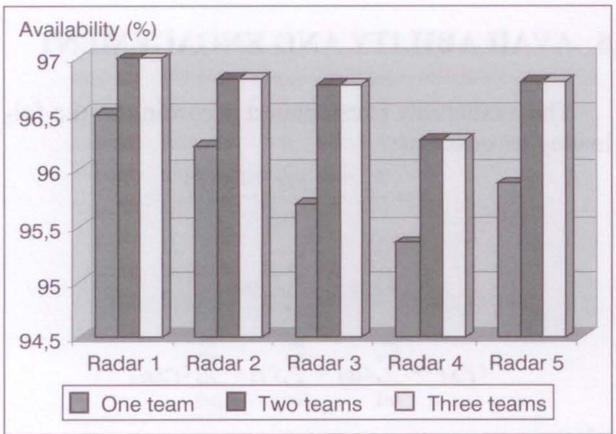
t_{PMi} – duration of i-th preventive maintenance,

t_{Ri} – duration of i-th rest,

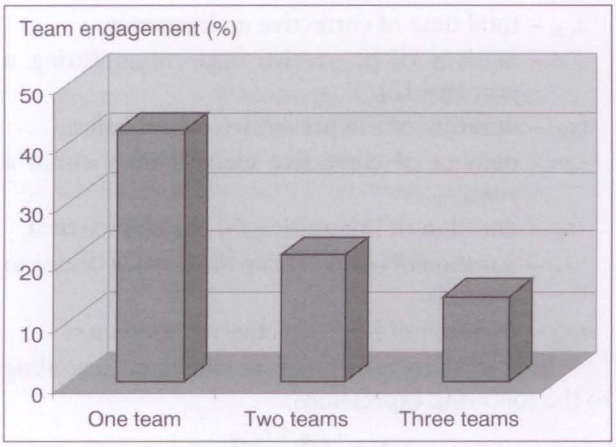
t_{TBi} – duration of i-th trip from radar to Serving centre,

t_{CMi} – duration of i-th corrective maintenance.

The availability of radars through a year (Graph 7) depends on the number of engaged teams. It is for one team very high, but, by introducing the second team it is increased. By introducing the third team the availability does not change. With the second team the maximum availability of the considered radar network is achieved.



Graph 7 – Availability of radar regarding the number of teams



Graph 8 – Engagement of a team over a year

The engagement of a single team over a year (Graph 8) is reduced with the number of introduced engaged teams. Since the considered time period in the simulated model is one year, i. e. 8760 hours, the teams are in case of one, two or three teams engaged 42 percent of time of simulation (3680 hours), 21 percent (1840 hours), that is 14 percent (1226 hours).

7. CONCLUSION

High availability of all the five radars (about 95 percent and more) in engagement of only one mobile team for preventive and corrective maintenance leads to the conclusion that such a serving model with thus defined preventive and corrective radar requirements would give satisfactory results and would function in practice (regardless of the fact that in individual cases over 80 hours was the waiting time for the availability of a team and some radars stayed out of operation for over 85 hours). However, one team is overloaded (works or is at radar location or travels 3680 hours in one year).

Simulation model which contains two teams reached the maximum availability both of the team and the radar. One of the teams is always available at the Serving centre and upon generated request of a radar start immediately towards the radar position. The team engagement is 1840 hours within a year, and the radar downtime is less than ten hours per generated downtime.

By introducing the third team the proper functioning and radar availability have not been increased nor has the waiting time for the available team at the Serving centre been reduced (maximum was achieved with two teams), but the engagement of a single team has been reduced (1226 hours in a year).

The so defined simulated serving model has indicated that two teams satisfy and timely serve the generated preventive and corrective radar requests. It is to be assumed that in practice the team members will take sick-leave, attend training, courses, etc. This has not been planned in the simulation, but it will certainly occur in practice. Neither does the simulation predict the possible "office" jobs of the team(s) (e. g. reporting on the carried out works). If this was taken into consideration the optimal number of teams in such a simulated model would be three.

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SAŽETAK

SIMULACIJSKI MODEL LOGISTIČKE POTPORE IZDVOJENIH RADARSKIH POSTAJA ZA KONTROLU ZRAČNOG PROSTORA

Izrađen je simulacijski model rada radarske mreže pet vojnih radarskih postaja. Simulacija je izvedena u GPSS jeziku, a sadrži vrijeme rada pet radara kroz godinu dana, vrijeme planiranog preventivnog održavanja, neispravnosti, vrijeme korektivnog održavanje te tim(ove) za održavanje. Simulacija pokazuje utjecaj broja timova za održavanje na raspoloživost svakog pojedinog radara i dobar je orijentir za definiranje optimalnog modela preventivnog i korektivnog održavanja radarske mreže.

KLJUČNE RIJEČI

radar, tim, održavanje, diskretni događaji, GPSS

LITERATURE

[1] **Barković, M.**: *Logistička potpora elektroničkim sustavima*, FPZ, Zagreb, 1998.

[2] **Blanchard, Benjamin S.**: *Logistics engineering and management*, Prentice Hall Inc., New Jersey, 1986.

[3] **Čerić, V.**: *Simulacijsko modeliranje*, Sveučilište u Zagrebu, Školska knjiga, Zagreb, 1993.

[4] *Dugoročni plan razvoja oružanih snaga Republike Hrvatske 2006. - 2015.*, Ministarstvo obrane Republike Hrvatske, Zagreb, June 2006

[5] -: *Lessons for WebGPSS/Micro-GPSS*, Stockholm school of economics.

[6] -: MIL-HDBK-338B, *Eelectronic reliability design handbook*, DoD, USA, 1998.

[7] **Raivio T.**: *A simulation model for military aircraft maintenance and availability*, European Simulation Multiconference, Prague, Czech, 6-9 June 2001

[8] **Sturgul, John R.**: *Mine design using simulation*, University of Idaho

[9] **Zelenika, R.**: *Metodologija i tehnologija izrade znanstvenog i stručnog djela*, Ekonomski fakultet, Rijeka, 1998

[10] Web site, http://www.lockheedmartin.com/data/assets/7152.pdf