Improving probability distributions for resource levels from master surgery tactical plans for emergency and elective patients.

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ABSTRACT

Efficiency and patient satisfaction are two of the most important factors for a hospital; in order to be competitive these two factors have to be improved. Tactical admission plans are focused on increasing efficiency, but in this paper we try to also associate patient satisfaction with the tactical plan. To this respect, we present a procedure to calculate exact waiting time distributions and another procedure to compute the exact level of resources usage. Then we explore two different methods to improve tactical plans to avoid overuse of IC beds, we consider this as the most critical resource: cancellation of emergency patients operations and cancellation of elective patients operations. Data from a Dutch cardiothoracic surgery center is used to base our case study on and shows that the cancelation of operation leads to an increase of hospital efficiency but it can have some negative effects in the patient satisfaction.

SUMMARY

1. INTRODUCTION

A public or private hospital can be considered as a multi-service production system, which is constrained by finite capacity of material and human resources. Its objective is to offer the best health care at the lowest cost (Guinet and Chaabane (2003)). There are three different ways in which patients can enter in a hospital; Adan and Vissers (2002): as an outpatient after a referral from a general practitioner, as an emergency patient in case of immediate need of specialist treatment and as an impatient. The impatient admissions can be divided in scheduled and non-scheduled. Scheduled or elective patients are selected from a waiting list or are given an appointment for an admissions date. Non-scheduled inpatient or emergency admissions concern patients that are immediately admitted. Dealing with this last type of patients, emergency patients, may amount to determining the level of capacity required to operate a pattern of elective patients so as to keep the deferral rate as low as possible (Adan et al. (2011)). Some example found in the previous literature related to this subject are: Utley et al. (2003) in which they estimate the bed occupancy depending on the arrivals of elective and emergency patients using generating functions and Lamiri et al. (2008) who deal with elective and emergency demand for surgery developing a stochastic model for operating room planning.

The minimization of the variability would have a positive impact on the productivity of the hospital and it is one of the major concerns (Beliën and Demeulemeester (2007)). Recent studies, like McManus et al. (2003), have given proof that this is possible. In the first study they define two different kinds of variability, natural variability and artificial variability. The main difference between them is the cause that provokes it. Natural variability is due to the uncertainty in patient arrivals, recovery time, etc. while for artificial variability poor scheduling polices are the cause. The artificial variability could be reduced by exact and/or heuristic algorithms (Beliën and Demeulemeester (2007)). This last type can be improved by the application of a queuing model approach (McManus et al. (2004)), which could help in the optimization of the bed occupancy in intensive care unit.

One of the most expensive and critical resources is the operating theater, that together with the waiting list, are the focus of most of the previous literature in this field. For example, in the overview of the research on admission planning presented by Gemmel and Van Dierdonck (1999), it is remarkable how almost all the studies are directed on the optimization of the resources and the scheduling at an operational level.

Other resources such as the number of beds are also regarded as critical, for instance Beliën and Demeulemeester (2007), Ridge et al. (1998), Utley et al. (2003). Besides the number of beds and the operating theater, there are other multiple resources which could be considered as critical. Adan and Vissers (2002) develop a model in which the nursing hours, the number of beds in the Medium-care unit and in the Intensive-care unit and the capacity of the operating theater are all critical resources. This model's objective is the reduction of the deviations between resources consumption and target level by the creation of a planning mix of patients. Following the same line, Adan et al. (2009), carried out a study with additional restrictions in combinations of patients and availability of resources together with other assumptions on the stochastic variables. Dellaert and Jeunet (2008) consider that the bottleneck resources in a hospital may lead to surgery cancellations, and these are the operating theater, bed capacity and nursing in Intensive-care unit and bed occupancy in wards or Medium-care services. Their purpose is to determine a master schedule of the utilization of each resource. These papers have the purpose of creating a planning model only on a tactical level.

For being competitive, a hospital, should reach two goals: efficiency and patient satisfaction. Increasing efficiency is the purpose of tactical plans, but the quality of the service is not modified by this models and it should also be improved. Therefore, Dellaert et al. (2010) link both by creating probability distributions for waiting time and for the resources usage levels related with the tactical plan. According to the simulation results obtained of the study carried out by Adan et al. (2011) there is a trade-off between hospital efficiency and patient service. In this paper they develop a two-stage planning procedure for master planning of elective and emergency patients while optimizing the available hospital resources.

Our paper follows the same vein as Cayiroglu et al. (2010). The main difference is that we are going to develop the procedure with two different types of patients, elective and emergency patients, at the same time. Except for that, the aim of the paper is similar; we want to relate tactical plans with patient service. In order to achieve this we have created a procedure to calculate the probability distributions for waiting time, which derive from the tactical plan, and for the usage level of the other resources associated to the tactical plan. In order to avoid shortages of the IC beds we have studied two different possibilities. One consists of cancelling some of the emergency arrivals and the other is focused on cancelling some of the elective patients.

For our model we have considered as critical resources: operating theater daytime hours (OT), Intensive-care beds (IC), Intensive-care nursing hours (NH) and Medium-care beds (MC). Is important to remark that from the emergency patients only 1/3 of the operations are during the day, the rest of patients are operated on during the night or weekends, so we will not consider them as part of the critical resource. The case study is based on the functioning of the Thorax Center Rotterdam which is described in Adan et al. (2011). The resources use depends on patient pathology, which defines the service that the patient needs Guinet and Chaabane (2003). Therefore, we have grouped the patients in different categories. The patients in each category have a similar consumption of resources, the distribution of the length of stay in IC and MC units, the nursing hours required on a certain day and the duration of the operation, all of them based on observed values. One day before the operation some categories of patients are admitted in the MC unit. Then all the categories of patients are operated. After the surgery, most patients are relocated in the Intensive-care unit in which specialized nurses take care of them. Finally they have the possibility of be transferred to the Medium-care unit for a few days.

The remainder of this paper is organized as follows. In Section 2 we present the mathematical models for the tactical plan developed in Adan et al. (2011) and the distribution for the waiting time and the levels of resources usage from Cayiroglu et al. (2010). In Section 3 we provide two different strategies for limiting the IC bed shortages. To reduce the overuse of this resource we cancelled some of the operations, in the first approach we deal with cancellation of emergency patients while in the second we cancel electives from the most common category. In Section 4, data from the Thorax Center are used to test these procedures in terms of patient cancellations, waiting time and resources usage. Finally, in Section 5 the main conclusions of the paper are drawn.

2. MATHEMATICAL MODEL

2.1 Tactical plan

The problem faced by the OT management, in the medium-run, is determining a tactical admission plan for all elective patients. The aim is to allocate at best the major resources while operating on all patients that are expected during a "typical" horizon. It is formulated as a mixed integer linear program, and we obtained the formulation of it from Adan et al. (2011). The objective is to minimize deviations between expected utilizations of resources and some target consumptions as well as overuse of resources beyond the maximum capacities.

The parameters and variables adopted are defined in Table 1 and Table2.

Parameters	
N	Number of patients categories
c	Category index, $c=1,...,N$
T	Length of the cyclic planning horizon in days
t	Day index
V_c	Target number of elective patients of category to be operated during the horizon
s_c	Operation duration in hours for a patient of category c
l_c	Number of pre-operative day in MC unit for one patient of category c
r	Resource index, r={OT, IC, NH, MC}
$P_{IC,c,j}$	Probability that a patient from category c is (still) at the IC unit j days after operation, $j = 0,1,2,...,L_{IC}^{max}$
$\boldsymbol{L_{IC}^{max}}$	Maximum length of stay recorded in IC over all categories
$P_{MC,c,j}$	Probability that a patient from category is at the MC unit days after operation, $j = 0,1,2,...,L_{MC}^{max}$
$\boldsymbol{L_{MC}^{max}}$	Maximum length of stay recorded in MC over all categories
$w_{c,j}$	IC nursing workload (in hours) required for a patient of category c, j days after operation
$C_{r,t}$	Maximum capacity for resource r on day t (expressed in number of hours for OT and NH and in number of beds for IC and MC)
$R_{r,t}$	Target utilization of resource r on day t
$\beta_{c,t}$	Arrival rate for emergency patient of category c on day t
$q_{r,t}$	Probability that an emergency patient of group c arrives during the day t and not during the night
α_r	Relative importance of resource r as assessed by the stakeholders in the hospital

Table 1: Parameters

Variables	
$\boldsymbol{X_{c,t}}$	Number of patients from category c to be operated on day t, with c=1,…,N and t=1,…,T
$\boldsymbol{O_{r,t}}$	Overutilization of resources relative to the target utilization of resource r on day t, r={OT, IC, NH, MC} and t=1,…,T

$U_{r,t}$	Underutilization of resources relative to the target utilization of resource r on day t, r={OT, IC, NH, MC} and t=1,…,T
$E_{r,t}$	Overuse of resource r on day t compared to the maximum capacity

Table 2: Variables

It is important to mention that the target utilization $\{R_{r,t}\}$ includes capacity for emergencies. The objective is to determine the value of the variable $\{X_{c,t}\}$ satisfying certain constraints and for which the daily expected utilization of each resource deviates as little as possible from the daily target consumption. And, the planning of patients $\{X_{c,t}\}$, must also minimize the overuse of resources relative to the maximum capacities. Therefore, the objective function to be minimized can be written as

$$\sum_{r=\{\text{OT,IC,NH,MC}\}} \alpha_r \sum_{t=1}^{T} (O_{r,t} + U_{r,t} + E_{r,t} \cdot b) \tag{1}$$

where $b\geq 0$ is a constant penalizing capacity excess.

The total number of patients of group c to be operated over the T-day cycle should be equal to the target patient throughput Vc. Hence

$$\sum_{t=1}^{T} X_{c,t} = V_c \quad c = 1, \dots, N \tag{2}$$

The expected utilization of the OT by both elective and emergency patients must satisfy

$$\begin{aligned} \sum_{c=1}^{N} s_c X_{c,t} + \sum_{c=1}^{N} s_c q_{c,t}\beta_{c,t} &\leq C_{OT,t} + E_{OT,t} \quad t = 1, \dots, T \\ &\leq R_{OT,t} + O_{OT,t} \quad t = 1, \dots, T \\ &\geq R_{OT,t} - U_{OT,t} \quad t = 1, \dots, T \end{aligned} \tag{3}$$

The expected number of beds in IC must also satisfy the three following inequalities

$$\begin{aligned} \sum_{c=1}^{N} \sum_{j=0}^{L_{IC}^{max}} p_{IC,c,j} X_{c,t-j} + \sum_{c=1}^{N} \sum_{j=0}^{L_{IC}^{max}} p_{IC,c,j}\beta_{c,t-j} &\leq C_{IC,t} + E_{IC,t} \quad t = 1, \dots, T \\ &\leq R_{IC,t} + O_{IC,t} \quad t = 1, \dots, T \\ &\geq R_{IC,t} - U_{IC,t} \quad t = 1, \dots, T \end{aligned} \tag{4}$$

In the above constrains we used the convention that the subscript t-j in $X_{c,t-j}$ should be treated modulo T: day 0 in the same as day T, day -1 in the same as day T-1 and so on. For the expected number of nursing hours in IC, we must have

$$\begin{aligned} \sum_{c=1}^{N} \sum_{j=0}^{L_{IC}^{max}} w_{c,j} p_{IC,c,j} X_{c,t-j} + \sum_{c=1}^{N} \sum_{j=0}^{L_{IC}^{max}} w_{c,j} p_{IC,c,j}\beta_{c,t-j} &\leq C_{NH,t} + E_{NH,t} \quad t = 1, \dots, T \\ &\leq R_{NH,t} + O_{NH,t} \quad t = 1, \dots, T \\ &\geq R_{NH,t} - U_{NH,t} \quad t = 1, \dots, T \end{aligned} \tag{5}$$

Similarly, the expected number of beds in MC must satisfy

$$\sum_{c=1}^{N}\sum_{j=1}^{l_c} X_{c,t+j} + \sum_{c=1}^{N}\sum_{j=0}^{L_{MC}^{max}} p_{MC,c,j} X_{c,t-j} + \sum_{c=1}^{N}\sum_{j=0}^{L_{MC}^{max}} p_{MC,c,j}\beta_{c,t-j} \le C_{MC,t} + E_{MC,t} \quad t = 1, \dots, T$$

$$\le R_{MC,t} + O_{MC,t} \quad t = 1, \dots, T$$

$$\ge R_{MC,t} - U_{MC,t} \quad t = 1, \dots, T$$

(6)

As operating rooms on weekends are dedicated only to emergency patients, we have to require that

$X_{c,t} = 0$ and $X_{c,t+1} = 0$ $t = 6+7\cdot(j-1)$; $j = 1,\dots,(T/7)$; $c = 1,\dots,N$ (7)

Our planning problem therefore consists of minimizing the objective function in (1) subject to constraints (2) to (7) and the integrality constraints (8):

$X_{c,t}$ □ $\{0,1,2,\dots\}$, $c = 1,\dots,N$; $t = 1,\dots,T$ (8)

In the following section we refer to this model as the “basic” mathematical model. The procedure to compute the waiting time associated with any tactical plan will be presented in the following section.

2.2 Calculation of the waiting time

Now we will approach the problem from the operational level. The waiting times of elective patients have an importance in the performance of the system, but they are not considered in the mathematical model for the tactical plan.

For this section we will follow the previous study of Dellaert, et al. (2010). The procedure for the distributions for the waiting time is the same, due to the fact that the emergency arrivals don't interfere in it. So the waiting time will only refer to the elective patients.

The calculation of the waiting time is developed for each category separately, because of the assumption that the operations of each category of patients are independent from each other. For this calculation the steady-state probabilities of the patient queue for every patient category for every working day is needed. This queue is described as a Markov process, where the number increases by daily patient arrivals and decreases on operation days. The number of patient arrivals per day assumed to follow a Poisson distribution. This is a common assumption (see Swartzman (1970)) and the Poisson arrival hypothesis was not rejected in our case study. The probability that the number of patients of category *c* before operation on day *t* equals $q_{c,t}^{bo}$ is denoted by $Q_{c,t}^{bo}\left(q_{c,t}^{bo}\right)$. The decisions about the operational plan are assumed to be taken 7 days in advance, to be able to inform patients and hospital staff in time. The number of planned operations on day t, $X_{c,t}$, has been determined on day *t*-7. The number of patients operated on day *t* equals to $\min(q_{c,t-7}^{bo}, X_{c,t})$. So, we operate all the patients in the queue when the number of patients in queue, $q_{c,t-7}^{bo}$, is less than or equal to the number of planned patients. Therefore, the number of patients that are not operated on after the operation session equals $q_{c,t}^{no} = q_{c,t-7}^{bo} - \min(q_{c,t-7}^{bo}, X_{c,t})$ with probability $Q_{c,t}^{no}(q_{c,t}^{no})$. The number of patients before operation on day *t* is $q_{c,t}^{bo} = n_c + q_{c,t-1}^{no}$, where n_c is Poisson distributed. We use a successive iteration method until the values of $Q_{c,t}^{no}(q_{c,t}^{no})$ and $Q_{c,t}^{bo}(q_{c,t}^{bo})$ reach their steady state. Obtaining the steady state probabilities allows for the calculation of the average waiting time for each patient category.

The waiting time of patients of each category, WT_c, is determined with the queue of patients in each day, $Q_{c,t}^{bo}(q_{c,t}^{bo})$, the number of patients in this queue, $q_{c,t-7}^{bo}$, the number of days they have to wait before being operated on and the arrival rate. Let $d_{c,t}$ be the number of days between operation day *t* for category *c* and the next consecutive operation day *t'*, with $t' \geq t+1$. For all $t = 1, \ldots, T$, the number of days $d_{c,t}$ is thus defined as follows: if there is no operation for category *c* on day *t*, we set $d_{c,t} = 0$, otherwise we have $d_{c,t} = t' - t$. Let λ_c be the arrival rate of patients of category *c* per day and let $\lambda_c T$ be the arrival rate of patients over the whole planning horizon. We get for each patients category

$$WT_c = \frac{\sum_{\{t|X_{c,t}>0\}} \sum_{q_{c,t-7}^{bo}>0} q_{c,t-7}^{bo} \cdot Q_{c,t-7}^{bo}(q_{c,t-7}^{bo}) \cdot d_{c,t}}{\lambda_c T} \qquad (10)$$

In the next part we are going to determine the distributions for the resources usage levels, using the steady state probabilities, of queued elective patients.

2.3 Calculations for the resources usage levels

To develop the calculations for the usage levels of IC and MC beds, the nursing hours in the IC unit and the OT daytime hours, we are going to use the same steady state probabilities as in the calculation of the waiting time distributions. Below is the detailed procedure for the calculation of the distribution of the intensive care unit usage. The methods used to obtain the distribution for the other resources, MC beds, nursing hours and OT daytime hours, are similar so we are not going to explain them.

The formulation of this part is also similar to the one used in Cayiroglu et al. (2010), but in this case we also have to add the emergency patients.

The algorithm

To determine the distribution for the number of IC beds we used an algorithm which consists of four steps, detailed below.

Step 1. Let $E_{c,t}$ be the probability of having $e_{c,t}$ emergency patients arriving on day *t* of category *c*. These arrivals are assumed to follow a Poisson distribution. The maximum number of possible operations per day, including the number of planned operations for electives and the emergency operations, will be represented by *maxop*. And let $S_c(n,t)$ be the probability that n operations of category *c* take place on day *t*. On each day $t = 1, \dots, T$ and for each category $c = 1, \dots, N$, we

$$S_c(n,t) = \sum_{r=0}^{n} Q_{c,t-7}^{bo}(n-r) \cdot E_{c,t}(r) \ \ \forall n = 0, \dots, maxop-1 \ and \ n-r \leq X_{c,t}$$

$$S_c\left(X_{c,t}+r,t\right) = \sum_{r=0}^{n} Q_{c,t-7}^{bo}(n-r) \cdot E_{c,t}(r) \ \ \forall n = 0, \dots, maxop-1 \ and \ n-r > X_{c,t}$$

$$S_c(maxop,t) = 1 - \sum_{k=0}^{maxop-1} \sum_{r=0}^{k} Q_{c,t-7}^{bo}(k-r) \cdot E_{c,t}(r)$$

(11)

If the number of patients in the queue, *n-r*, plus the number of emergency arrivals, *r*, is less than the maximum number of operations that can be done in one day (*maxop*) and the number of patients in queue is smaller or equal to the number of planned patients, $X_{c,t}$, then we operate on all *n* patients, electives plus emergencies, with the probability there are *n-r* patients in queue and the probability of having *r* emergency arrivals. While, if in the same situation the number of patients in queue is bigger than the number of planned patients we only operate on r+$X_{c,t}$ patients. If the number n of patients exceeds or equals this limitation $maxop$, we operate on $maxop$ patients.

Step 2. Let P_c (*n* ,*t* ,*j*) be the probability that there are *n* patients of category *c* staying at the IC unit after *j* days from their surgery, which took place on day *t*. This probability can be easily derived by considering a binomial distribution based on the probability that an individual patient is in IC on this specific day. For each category $c = 1, \dots N$, for all $t = 1, \dots, T$ and for all $j = 0, \dots, L_{IC,c}^{max}$, we have

$$P_c(n,t,j) = \begin{cases} \sum_{k=n}^{maxop} \binom{k}{n} S_c(k,t) \cdot p_{IC,c,j}{}^{n} \cdot (1-p_{IC,c,j})^{k-n} & if\ n \le maxop \\ 0 & otherwise \end{cases}$$

(12)

Step 3. Let TP_c (n, t, j) be the probability that on day *t* there are exactly *n* patients of category *c* in the IC unit who will stay at least *j* more days. Let $R_c(n,t)$ be the probability there are exactly *n* patients of category *c* in the IC unit on day *t*. Obviously, for all *n* and $t = 1, \ldots, T$, we have for each category $c = 1, \ldots, N$

$$R_c(n,t) = TP_c(n,t,0)$$

(13)

The *n* patients that are in the IC unit on day *t* consist of a set of patients that have been operated in the last $L_{IC,c}^{max}$ periods. In order to calculate $R_c(n,t)$, we adopt a recursive reasoning: to have exactly *n* patients in IC on day *t* staying at least for *j* days, we must have *n* patients in IC on day *t*-1 staying at least for *j*+1 days and zero patients operated on day *t*; or *n*-1 patients in IC on day *t*-1 (staying at least for *j*+1 days) and 1 patient operated on day *t* staying for *j* days; or *n*-2 patients in IC on day *t*-1 and 2 patients operated on day *t* staying for *j* days, etc. We thus have for all *n* and $t = 1, \ldots, T$

$$TP_c(n,t,j) = \sum_{k=0}^{n} TP_c(n-k, t-1, j+1) \cdot P_c(k,t,j)$$

(14)

As a starting point, we take for all possible *n* values

$$TP_c\left(n, t - L_{IC,c}^{max}, L_{IC,c}^{max}\right) = P_c(n, t - L_{IC,c}^{max}, L_{IC,c}^{max})$$

(15)

Step 4. Once the probabilities of IC usage levels for each category have been determined in this way, they are combined to obtain the overall usage of IC beds. A similar procedure is employed to do the summation over the categories. Formally, we let *R*(*n, t*) be the probability there are exactly *n* patients at the IC unit on day *t*. Again, we use a temporary variable, namely *TR*(*n, t, c'*), to be used for the recursive calculations, where *c'* means that categories $c = 1, \ldots, c'$ are taken into account in the computation. For all number of patients *n* and $t = 1, \ldots, T$, we have

$$R(n,t) = TR(n,t,N)$$

$$TR(n,t,c') = \sum_{k=0}^{n} TR(n-k, t, c'-1) \cdot R_{c'}(k,t)$$

(16)

As a starting point, we take for all possible *n* values

$$TR(n,t,1) = R_1(n,t)$$

(17)

A similar procedure is developed to get the usage levels of MC beds and nursing hours in the IC unit.
For the distribution of the OT hours there is a slight difference in the first step. Only 1/3 of the emergency patients are operated on during the day, the other 2/3 are operated during the night So in the S_c used for

the calculation of the daytime OT hours we only considered the emergency patients that arrive during the day. The other steps are similar to the ones described for the IC beds usage levels.

3. CANCELLATIONS OF OPERATIONS

In the previous literature in admission strategies, the studies have focused on reducing the waiting time after the application of the tactical plan. For instance, Adan et al. (2011), Dellaert and Jeunet (2008) and Cayiroglu et al. (2010) consider the slack planning strategy with the intent of reducing the waiting time.

Although waiting time is one of the most important factors in a hospital, we should keep in mind that the optimization of the levels of resources utilization is considered as an indicator of the hospital efficiency. In order to improve the efficiency we are going to carry out two different models based on the cancellation of some kind of patient operations, emergencies in the first model and electives of one category in the second. The decisions of cancelling are taken according to the usage level of the bed occupancy in the IC unit. We choose this resource due to the fact that nearly all the patients have to stay there at least one day after the operation, so is the most busy resource. It is also the resource for which temporary expansion is the most difficult one.

3.1. Cancellation of emergency patients

The first method to improve the usage level of the IC beds we are going to describe is the cancellation of emergency patients operations. Let $R_{IC,t}$ be the decision variable used to limit the number of IC beds available. Like we mentioned above, the intention is to calculate the new distribution of admitted emergency patients based on this $R_{IC,t}$ level, in order to avoid the overuse of the beds at the IC unit.

The procedure consists of the following 5 steps. In the first three steps we calculate the IC-use considering all elective patients admitted in the last L_{IC}^{max} days and the emergencies patients until the day before. Then in Step 4 we determinate the distribution for the admitted emergency patients. And finally we will calculate the number of canceled patients.

Step 1. We start by recalculating the distributions for the usage level of IC beds. This time we are not going to include the emergency arrivals. The algorithm is the same as in Cayiroglu et al. (2010), that is to say, is similar to the one described in the section above but with a small difference in the calculation of the probability that *n* operations of category *c* take place on day *t*, $S_c(n, t)$. So the first step of this algorithm now is

$$S_c(n,t) = Q_{c,t-7}^{bo}(n) \;\; \forall n = 0, \dots, X_{c,t} - 1$$

$$S_c(X_{c,t}, t) = 1 - \sum_{k=0}^{X_{c,t}-1} Q_{c,t-7}^{bo}(k)$$

(18)

If the number *n* of patients in the queue is less than the number of planned patients, then we operate on all *n* patients with the probability there are *n* patients in the queue. If the number of patients in the queue exceeds or equals the number of planned patients $X_{c,t}$, we operate on $X_{c,t}$ patients (with the probability that there are at least $X_{c,t}$ patients in the queue).

For the calculation of this probability, we used equations (12) to (17).

From now on the steps are going to be part of a cycle, that means we are going to perform the steps as many times as it is required until we reach a steady state for the values of the new $E_{c,t}$.

Step 2. In this step we are going to determine the $Pp_c(n, t)$ that is the probability that there are *n* patients at the IC unit on day *t*. For determining this distribution we have to follow this algorithm:

We start by determining the $PE_c(n, t, j)$ that is the probability that there are *n* emergency patients of category *c* staying at the IC unit after *j* days from their surgery, which took place on day *t*. This probability is considered a binomial distribution based on the probability that an individual patient is in IC on this specific day. Let $E'_c(n,t)$ be the probability there are *n* emergency patients admitted on day *t*. We determine this value for each category $c = 1, \dots, N$, for all $t = 1, \dots, T$ and for all $j = 0, \dots, L_{IC,c}^{max}$

$$PE_c(n,t,j) = \begin{cases} \sum_{k=n}^{maxIC} \binom{k}{n} E'_c(k,t) \cdot p_{IC,c,j}{}^{n} \cdot (1-p_{IC,c,j})^{k-n} & if\ n \le maxIC \\ 0 & otherwise \end{cases}$$

(19)

Where *maxIC* is the maximum number of admitted patients that can be accepted in the IC unit. The reasoning applied is the same as for equation (12), explained in the previous section.

As a starting point, we let for all possible *n* values and for all the *c* categories

$$E'_c(n,t) = 0$$

(20)

Afterwards we calculate $Pp_c(n, t)$ that is the probability there are exactly *n* patients of category *c* in the IC unit on day *t*. Let $TP_c(n, t, j)$ be the probability that on day *t* there are exactly *n* patients of category *c* in the IC unit who will stay at least *j* more days. On day t the n patients that are in the IC unit consist on the patients operated on in the last $L_{IC,c}^{max}$ periods. To develop the calculation of $TP_c(n, t)$ we are going to adopt the same recursive reasoning again.: For all *n* and $t = 1, \dots, T$ we have for each category $c = 1, \dots, N$

$$Pp_c(n,t) = TP_c(n,t,0)$$

$$TP_c(n,t,j) = \sum_{k=0}^{n} TP_c(n-k, t-1, j+1) \cdot PE_c(\mathrm{k,t,j})$$

(21)

As a starting point, we take for all possible *n* values

$$TP_c\left(n, t - L_{IC,c}^{max}, L_{IC,c}^{max}\right) = PE_c(n, t - L_{IC,c}^{max}, L_{IC,c}^{max})$$

(22)

Step 3. Then we calculate the total number of beds occupied in the IC unit. Let $Pb_c(n, t)$ be the probability there are *n* patients in the IC unit on day *t* before adding the arrivals of category *c*.

There are different ways of calculating this value, depending on the category *c* and the day *t*. For category 1 we thus have, for all *n* and $t = 1, \dots, T$,

$$Pb_1(n,t) = \sum_{k=0}^{n} R(n-k,t)\, Pp_1(k,t)$$

(23)

As a starting point, we let for all the possible *n* values

$$Pb_1(n,1) = R(n,1)$$

(24)

For all the other *c* categories, for all *n* and $t = 1, \dots, T$ we have

$$Pb_c(n,t) = \sum_{k=0}^{n} Pb_{c-1}(n-k,t)E'_{c-1}(k,t)$$

(25)

Step 4. Now we are going to determine the new value of $E'_c(n,t)$, the probability that *n* emergency patients of category *c* can be admitted on day *t*. It is important to remind that $E_c(n,t)$ is the probability that *n* emergency patients of category *c* arrive on day *t*. The value of $C_{IC,t}$ is given, this capacity value is set such that it is almost impossible to exceed, even without any kind of cancellations. For all $t = 1, \dots, T$ and all n values we have

$$E'_c(n,t) = \sum_{k=0}^{C_{IC,t}} Ec(n,t)\mathrm{Pb_c}\ (k,t) \quad if\ n+k \le R_{IC,t}$$

$$E'_c(R_{IC,t}-k,t) = \sum_{k=0}^{C_{IC,t}} E_c\ (n,t)Pb_c(k,t) \quad if\ \ n+k > R_{IC,t}\ and\ k < R_{IC,t}$$

$$E'_c(0,t) = \sum_{k \ge R_{IC,t}}^{C_{IC,t}} Pb_c(k,t)$$

(26)

If the number of patients arriving *n* plus the number of occupied beds *k* is smaller of equal to the maximum capacity of beds at the IC unit on day *t*, $R_{IC,t}$, we admit all *n* emergency patients. Otherwise, if the number of beds occupied *k* is smaller than the maximum capacity, $R_{IC,t}$, on day *t* then we admit only $R_{IC,t} - k$ emergency patients. And finally, if none of the previous requirements is true we admit 0 emergency patients. In this case, the cancelled patients are not relevant for future days. The fact that they are emergency patients means that if they are not admitted in this hospital they go to another one.

Step 5. Finally we will calculate the number of canceled patients on a certain day. Let $Pcanc_c(n,t)$ be the probability that there are *n* emergency patients canceled on day *t*. We determine this value for each category $c = 1, \dots, N$ and for all $t = 1, \dots, T$

$$Pcanc_c(j,t) = \sum_{j=0}^{C_{IC,c}} j \cdot (E_c(j,t) - E'_c(j,t))$$

(27)

Once we have the new distribution for the admitted emergency patients, $E'_c(n,t)$, which represents the probability that there are *n* emergency patients of category *c* admitted on day *t*, we calculate the new levels of usage of the resources. The algorithm used is the same as the one described in section 2.3.

3.2. Cancellation of electives of category 3

The second method is focused on the cancellation of electives of category 3. We choose this category because it is the one that has the most planned operations. The purpose is the same mentioned above, to avoid the overuse of beds in the IC unit by calculating a new distribution for admitted patients of category 3. Different from the cancelled emergency patient procedure, the cancelled electives will return to the waiting queue. Our decision parameter is $R_{IC,t}$, so we cancel electives of category 3 if otherwise we would uses more than $R_{IC,t}$ IC beds.

This procedure will be divided in 6 steps. In the first two steps we calculate the IC-use considering all emergency patients and all electives except category 3. We also introduce a queue of patients whose operation is delayed. Then we start a cycle in which the first step, Step 3, is to add the patients in the delayed queue to the arriving patients. Afterwards we will calculate the bed occupancy, considering the IC-use calculated in the first steps and all the total patients from category 3 from the last days. In step 6 we calculate the distribution of admitted patients for category 3 and on Step 7 the new queue of delayed patients and in Step 8 the amount of expected canceled patients for each day. Finally we recalculate the distributions for the waiting time and usage of resources.

Step 1. The first step is the definition of the new S_c (n,t) without elective patients of category 3. So the calculation is divided in two, for all categories c except for 3 we use equation (11) and for category 3 we are only going to consider the emergency arrivals, so for all $t = 1, \dots, T$ and all n we have

$$S_3(n,t) = E_3(n,t)$$

(28)

Step 2. Once we have the new S_c (n,t) we are going to use it to determine the new distribution of usage level for the IC beds. For the calculation we are going to use equations from (12) to (17) described earlier.

From now on the steps are going to be part of a cycle, that means we are going to perform the steps as many times as it is required until we reach a steady state of the values of $S'_3(n,\ t)$ which will be defined below.

Step 3. Let S''_3 (n,t) be the probability there are n patients of electives of category 3 on day t, in this we include the new arrivals of day t plus the queue from the previous days. And let $QC(n,t)$ the probability there are n patients on queue on day t. $S'_3(n,\ t)$ probability that n admitted elective patients of category 3 on day t. So for all n and for all $t = 1, \dots, T$ we have

$$S''_3(n,t) = \sum_{k=0}^{n} S'_3\,(k,t)QC(n-k,t)$$

(29)

As a starting point, for $S'_3(n, t)$ we will use equation (18) and while for the queue, we let for all possible *n* values

$$QC(n,t) = 0$$

(30)

Step 4. Let S'_3 (n,t) be the probability there are *n* admitted patients of electives of category 3 on day *t*. In this step we are going to determine the $Pp_3(n, t)$ that is the probability that there are *n* patients of category 3 at the IC unit on day *t*.

We start by determining the $P_3(n, t, j)$ that is the probability that there are *n* elective patients of category 3 staying at the IC unit after *j* days from their surgery, which took place on day *t*. This probability is considered a binomial distribution based on the probability that an individual patient is in IC on this specific day. We determine this value for all $t = 1, \ldots, T$ and for all $j = 0, \ldots, L_{IC,3}^{max}$

$$P_3(n,t,j) = \begin{cases} \sum_{k=n}^{X_{3,t}} \binom{k}{n} S'_3(k,t) \cdot p_{IC,3,j}{}^{n} \cdot (1 - p_{IC,3,j})^{k-n} & if\ n \leq X_{3,t} \\ 0 \quad otherwise \end{cases}$$

(31)

The reasoning applied is the same as for equation (12), explained in the previous section.

Afterwards we calculate $Pp_3(n, t)$ that is the probability there are exactly *n* elective patients of category 3 in the IC unit on day *t*. Let $TP_3(n, t, j)$ be the probability that on day *t* there are exactly *n* patients of category 3 in the IC unit who will stay at least *j* more days. On day *t* the n patients that are in the IC unit consist on the patients operated on in the last $L_{IC,3}^{max}$ periods. For all *n* and $t = 1, \ldots, T$ we have for each category $c = 1, \ldots, N$

$$Pp_3(n,t) = TP_3(n,t,0)$$

$$TP_3(n,t,j) = \sum_{k=0}^{n} TP_3(n-k, t-1, j=1) \cdot P_3(\mathrm{k,t,j})$$

(32)

As a starting point, we left for all possible *n* values

$$TP_3\left(n, t - L_{IC,3}^{max}, L_{IC,3}^{max}\right) = P_3(n, t - L_{IC,3}^{max}, L_{IC,3}^{max})$$

(33)

Step 5. For the calculation of the total number of beds occupied in the IC unit we use the following equations. Let $Pb_3(n, t)$ be the probability there are *n* patients in the IC unit on day *t* before adding the arrivals of electives of category 3. For all *n* and $t = 1, \ldots, T$,

$$Pb_3(n,t) = \sum_{k=0}^{n} R(n-k,t)\, Pp_3(k,t)$$

(34)

Step 6. Now we are going to determine the new value of $S'_3(n,t)$, the probability that *n* elective patients of category 3 can be admitted on day *t*. It is important to remind that $S''_3(n,t)$ is the probability that *n* elective patients of category 3 are in IC unit on day *t*. For all $t = 1, \ldots, T$ and all n values we have

$$S'_3(n,t) = \sum_{k=0}^{C_{IC,t}} S''_3(n,t)\mathrm{Pb}_3\ (k,t) \quad if\ n+k \leq R_{IC,t}\ and\ if\ n \leq X_{3,t}$$

$$S'_3(X_{3,t},t) = \sum_{k=0}^{C_{IC,t}} S''_3(n,t)\mathrm{Pb}_3\ (k,t) \quad if\ n+k \leq R_{IC,t}\ and\ if\ n > X_{3,t}$$

$$S'_3(R_{IC,t}-k,t) = \sum_{k=0}^{C_{IC,t}} S''_3\,(n,t)Pb_3(k,t) \quad if\ n+k > R_{IC,t}, k < R_{IC,t}\ and\ if\ R_{IC,t}-k \leq X_{3,t}$$

$$S'_3(X_{3,t},t) = \sum_{k=0}^{C_{IC,t}} S''_3(n,t)\mathrm{Pb}_3\ (k,t) \quad if\ k < R_{IC,t}\ and\ if\ R_{IC,t}-k > X_{3,t}$$

$$S'_3(0,t) = \sum_{k=0}^{C_{IC,t}} S''_3\,(n,t)Pb_3(k,t)\ \ for\ all\ other\ cases$$

(35)

If the number of patients arriving *n* plus the number of occupied beds k is smaller or equal to the maximum capacity of beds at the IC unit on day *t*, $R_{IC,t}$, and the number of arriving patients *n* is smaller of equal to $X_{3,t}$ then we admit all *n* elective patients. If, on the other hand, the number of patients in queue *n* is bigger than $X_{3,t}$ we only admit $X_{3,t}$ patients, considering that *k*+*n* is smaller of equal to the maximum capacity. Otherwise, if the number of beds occupied *k* is smaller than the maximum capacity, $R_{IC,t}$, on day *t* and the difference, $R-k$, is smaller or equal to $X_{3,t}$ then we admit only $R_{IC,t}-k$ patients. But if this difference is bigger then we only admit $X_{3,t}$ patients. And finally, if none of the previous requirements is true we admit 0 category 3 elective patients. The ones who are not operated on a specific day will have to be operated some days later, but in the same hospital. To consider this we created the new queue for elective patients of category 3.

Step 7. In order to consider the fact we created a new queue of delayed patients we are going to specify the details to calculate it. Let $QC_3(n,t)$ be the probability there are *n* patients on queue on day *t* from the cancellations of previous days. For all *n* values and $t = 1, \ldots, T$ we have

$$QC_3(0,t+1)=\sum_{k=0}^{c_{IC,t}} S''_3(n,t)\mathrm{Pb}_3\ (k,t) \quad if\ n+k\le R_{IC,t}\ and\ if\ n\le X_{3,t}$$

$$QC_3\big(n-X_{3,t},t+1\big)=\sum_{k=0}^{c_{IC,t}} S''_3(n,t)\mathrm{Pb}_3\ (k,t) \quad if\ n+k\le R_{IC,t}\ and\ if\ n> X_{3,t}$$

$$QC_3\big(n-(R_{IC,t}-k),t+1\big)=\sum_{k=0}^{c_{IC,t}} S''_3\,(n,t)Pb_c(k,t) \quad if\ k< R_{IC,t}\ and\ if\ n> R_{IC,t}-k$$

$$QC_3(0,t+1)=\sum_{k=0}^{c_{IC,t}} S''_3\,(n,t)Pb_c(k,t) \quad if\ k< R_{IC,t}\ , if\ n\le R_{IC,t}-k\ and\ if\ R_{IC,t}-k\ \le X_{3,t}$$

$$QC_3\big(n-X_{3,t},t+1\big)=\sum_{k=0}^{c_{IC,t}} S''_3\,(n,t)Pb_c(k,t) \quad if\ k< R_{IC,t}\ , if\ n\le R_{IC,t}-k\ and\ if\ R_{IC,t}-k\ > X_{3,t}$$

$$QC_3(n,t+1)=\sum_{k=0}^{c_{IC,t}} S''_3\,(n,t)Pb_c(k,t)$$

(36)

If the number of patients in queue *n* plus the number of occupied beds *k* is smaller or equal to the target capacity of IC beds, $R_{IC,t}$, and *n* is smaller or equal to $X_{3,t}$, the number of patients added to the queue is 0. Instead if *n* is bigger than $X_{3,t}$, we add n-$X_{3,t}$ patients to the queue. If the number of beds occupied *j* is smaller than $R_{IC,t}$, considering that now *n+j* is bigger than this number, and *n* is smaller than *j*-$R_{IC,t}$ then we add *n*-(*j*-$R_{IC,t}$,) patients to the queue. In the other hand, if *n* is bigger than *j*-$R_{IC,t}$ we have two possibilities: first will be if *j*-$R_{IC,t}$ is smaller or equal to $X_{3,t}$ then we add 0 patients to the queue and the second is if *j*-$R_{IC,t}$ is bigger than $X_{3,t}$ then we add *n*-$X_{3,t}$ patients. Otherwise, if none of these requirements are true, then we add all *n* patients to the queue.

Step 8. Now we are going to determine the expected number of canceled patients. Let $Pcanc_c(n,t)$ be the probability that there are *n* emergency patients canceled on day *t*. We created a new constant, *maxq*, which is the maximum number of patients that can be in queue. We determine this value for each category $c=1,\dots,N$ and for all $t=1,\dots,T$:

$$Pcanc_3\big(R_{IC,t}+x-(j+l),t\big)=\sum_{x=0}^{X_{3,t}}\sum_{l=0}^{C_{IC,t}}\sum_{j=0}^{maxq} QC_3\,(j,t)\cdot S_3(x,t)\cdot Pb_3(l,t) \quad if\ \ R_{IC,t}+x-(j+l)>0$$

$$Pcanc_3(0,t)=\sum_{x=0}^{X_{3,t}}\sum_{l=0}^{C_{IC,t}}\sum_{j=0}^{maxq} QC_3\,(j,t)\cdot S_3(x,t)\cdot Pb_3(l,t)\ for\ the\ other\ cases$$

If the number of patients arriving on day t, x, plus the target capacity of IC beds, $R_{IC,t}$, is bigger or equal to the number of beds occupied, l, plus the number of patients in queue, j, then we have $R_{IC,t} + x - (j + l)$ canceled patients. While, for all the other possibilities, there will have 0 cancelations.

Step 9. Once we have the new values for the distribution of admitted patients of category 3 we are going to recalculate the distribution for the waiting time for this category. Due to the cancellations this values has increased, so we are going to use the previous calculation, equation (10) and then add the waiting time caused by the cancellations, *WC_3*.

$$WC_3 = \frac{\sum_{\{t|X_{c,t}>0\}} \sum_{n>0} QC(n,t) \cdot n \cdot d_{3,t}}{\lambda_3 T} \tag{37}$$

For the recalculation of the resources usage we used equations from (11) to (17), but we will use the value of the S'_3 instead of the S_3 obtained from equation (11).

4. CASE STUDY

The purpose is to assess on the waiting time and the resources consumption the impact of the cancellation of emergency patient operations and electives of category 3 operations by the application of the methods described in Section 3. We use three different tactical admission plans with the same inflow of elective patients but with different distributions for the arrival of electives (1, 2, 3), situation 1 has the minimum number of planned slots while number 3 is the one with the most number of planned slots. For each of them we have two distributions of emergency arrivals (a, b). The situations with letter b have the double inflow of emergencies than the ones with letter a. So we have six situations to analyze. We borrow the data of the Thorax Center from Adan et al. (2011) with a 28 day-horizon (T=28) and we assumed the arrival of patients for each of the 8 categories as a Poisson process. We did the procedure three times for each of the six situations; in each of them we changed the restriction for the IC beds. For the *a* situations the $R_{IC,t}$-values were 10, 9, and 8, while for the *b* situations were 11, 10, 9. The programs were solved using DELPHI.

The expected waiting time for elective patients only changes with the second method, the cancellation of electives of category 3. The new expected waiting time in that case was computed for the six situations and for each category of patients following Step 8 of the procedure described above, that is to say using equations (10) and (37). Then we obtained the average waiting time over all categories by summing up the expected waiting time of each category, multiplied by its frequency based on Poisson arrivals. In Table 3 the average of waiting time for the basic mathematical model and for the solutions, each of them with a different restriction of beds, to the method described are displayed, for each of the six situations mentioned above.

		1a	1b	2a	2b	3a	3b
BASIC MODEL		24.047	24.338	16.720	16.497	9.274	9.381
CANCELLATIONS CATEGORY 3	11 IC beds		26.883		19.030		11.720
	10 IC beds	25.522	29.122	18.251	21.199	10.618	13.917
	9 IC beds	26.256	45.286	19.081	37.233	11.618	29.201
	8 IC beds	28.621		23.791		15.440	

Table 3. Average waiting time

The average waiting time after the application of this method has increased. This consequence was expected because we are reducing the number of operations taking place in one day, which means that some of the patients will have to wait some days more. The stronger we fix the restriction, the smaller the number of IC beds, the bigger the waiting time. For all three situations, 1, 2, 3, if we double the number of emergencies (situations 1b, 2b, 3b) the average of waiting time with the IC bed restrictions grows faster, more IC beds are occupied and therefore we have more cancellations. For situation 3, the one with the most number of planned slots, the average of waiting time is the smallest of the three tactical plans. While for situations 1 is the bigger, this is coherent because when there are more slots available more patients can be accepted, so they have to wait for less time.

Now there are displayed some figures that represent the daily number of patients cancelled for each model and for the six situations. In Figure 1 we can find the results for the first method, cancellation of emergency operations for one cycle (28 days).

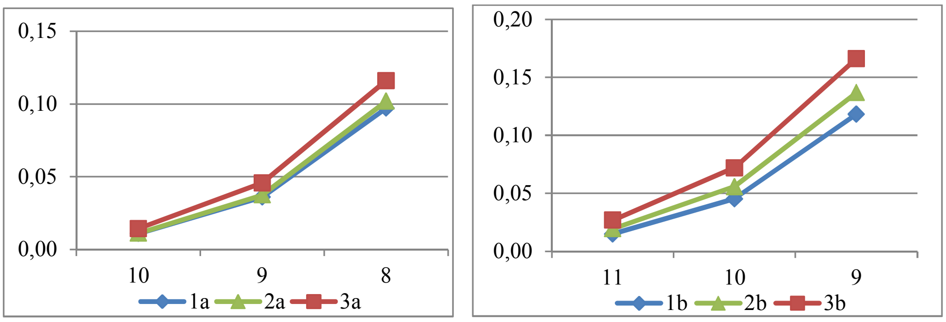

Figure 1: Emergency patients cancelled

While in Figure 2 we display the total daily number of patient cancellations with the second method, cancellation of elective of category 3 operations.

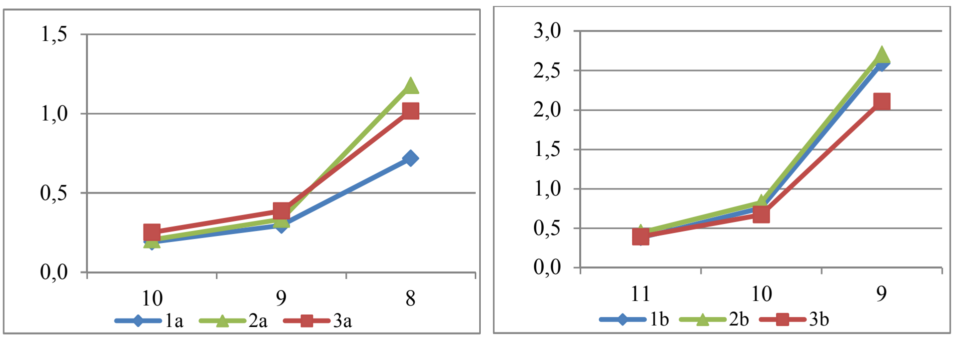

Figure 2: Elective operations cancelled for the second method

For all six situations the number of cancelled operations is bigger after the application of the second method. The expected number of cancellations when we make the restriction stronger increases almost exponentially in the three situation b (1b, 2b, 3b).

The computation of the resources usage was done using the procedure described in Section 3 for each of the two models. Then the over-utilizations and under-utilizations of these resources compared to the target levels were derived. The aim of the models was to reduce the over-utilization of the IC beds, the amount of IC beds that exceed the target level, in Figure 3 and Figure 4 there are displayed the different values for the daily over-utilization of this resource for the six situations described, each of them for three different restrictions:

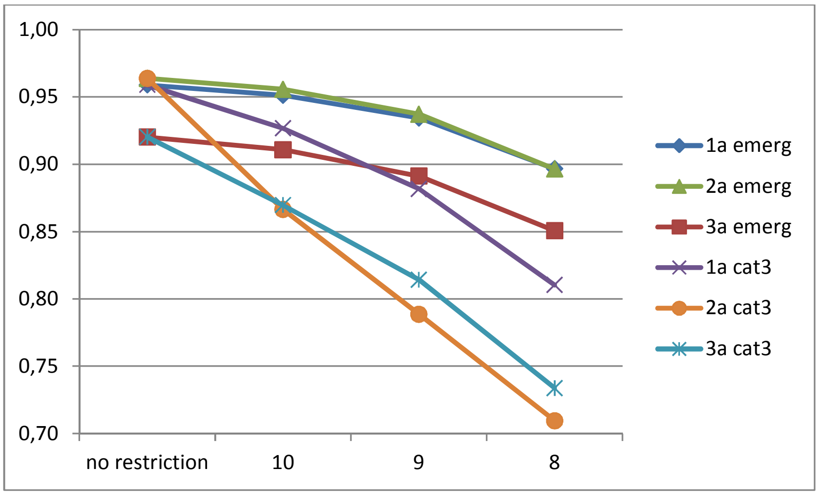

Figure 3: Over-utilization of IC beds for situation a

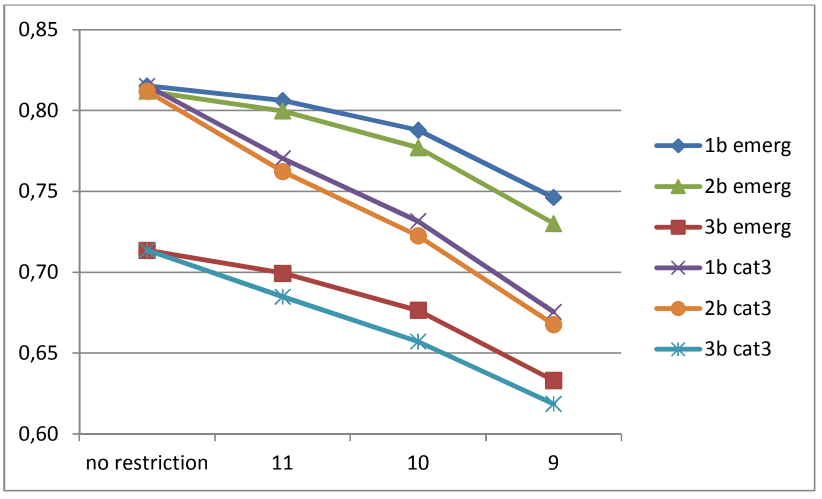

Figure 4: Over-utilization of IC beds for situation b

As expected, when the restriction of the IC beds is stronger the usage of the over-utilization of this resource decreases for each of the six situations. The reduction is more relevant after the application of the second method, cancellation of operations of category 3, and when the inflow of emergencies is smaller.

All the other resources have also experienced a change after the application of both models; we are going to display as an example the results for one of the six situations. The over-utilization referred to the target levels for one day of each resource is displayed in Table 4.

	OT		IC beds		NH		MC beds	
	Canc. emerg	Canc. Cat3	Canc. emerg	Canc. Cat3	Canc. emerg	Canc. Cat3	Canc. emerg	Canc. Cat3
No restriction	4.603	4.603	0.898	0.898	23.795	23.795	6.141	6.141
IC bed 10	4.541	4.445	0.951	0.927	23.132	22.912	5.652	5.482
IC bed 9	4.509	4.238	0.934	0.882	22.709	22.345	5.611	5.252
IC bed 8	4.426	3.912	0.897	0.810	21.719	21.441	5.508	4.883

Table 4: Over-utilization of the critical resources

In this example, like in all the other six situations studied, the over-utilization of the resources has decreased when adding the restriction for the new model. In this table we can see clear that all the critical resources experience a similar evolution to the IC bed occupancy, they all have experienced a reduction in the over-utilization.

Using the same situation as an example, the expected usage of all the resources is calculated. In Table 5 the values are displayed, we differentiated between the results for the weekends and for the other days of the week. The level of usage of almost all the resources is much lower during the weekend.

	OT				IC			
	Cancel cat. 3		Cancel emerg.		Cancel cat. 3		Cancel emerg.	
	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend
No restriction	1.440	26.834	1.440	26.834	5.531	6.589	5.531	6.589
IC bed 10	1.440	26.194	1.355	26.556	5.411	6.444	5.497	6.564
IC bed 9	1.440	25.456	1.305	26.535	5.244	6.290	5.423	6.506
IC bed 8	1.440	24.305	1.208	26.463	4.976	6.051	5.255	6.370

NH				MC			
Cancel cat. 3		Cancel emerg.		Cancel cat. 3		Cancel emerg.	
Weekend	No weekend	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend

No restriction	144.562	138.124	144.562	138.124	26.996	26.392	26.996	26.392
IC bed 10	143.136	136.395	143.913	137.590	26.350	25.713	26.941	26.323
IC bed 9	142.409	136.356	141.134	134.537	25.556	24.923	26.803	26.154
IC bed 8	137.938	131.675	138.862	133.383	24.272	23.681	26.454	25.734

Table 5: Expected values of resources use

In general, the trend followed by the values is to decrease when the restriction of the IC beds is stronger. These results are in accordance with the previous, displayed in Table 4, if the over-usage decreases the expected usage of the resources also.

In the same vein, the calculation of the variance of the critical resources usage level for this example was done. The variance is measures used in a set of numbers to calculate how spread out are from each other, how far they are from the expected value. The values for the weekend days were separated from the others and are analyzed apart. All these values are displayed in Table 6.

	OT				IC			
	Cancel cat. 3		Cancel emerg.		Cancel cat. 3		Cancel emerg.	
	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend
No restriction	9.653	19.503	9.653	19.503	2.867	5.663	2.867	5.664
IC bed 10	9.653	23.410	9.107	24.815	2.844	5.756	2.826	5.615
IC bed 9	9.653	27.420	8.771	24.019	2.813	5.846	2.745	5.513
IC bed 8	9.653	32.105	8.119	22.204	2.761	5.898	2.575	5.275

	NH				MC			
	Cancel cat. 3		Cancel emerg.		Cancel cat. 3		Cancel emerg.	
	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend	Weekend	No weekend
No restriction	979.916	2010.286	979.916	2010.286	95.146	85.307	95.146	85.307

IC bed 10	975.846	2009.251	964.396	1992.647	90.475	81.687	94.323	84.523
IC bed 9	970.107	2005.870	933.657	1954.018	85.620	77.776	92.668	82.976
IC bed 8	960.371	1987.814	867.097	1863.207	78.523	71.950	89.090	79.668

Table 6: Variance of the resources usage

Both strategies tend to reduce the variance of the resources, and when the restriction is stronger the value also decreases. Which means that if the limitation of IC beds is strong the set of values are closer to the expected usage of resources, the dispersion of the values is reduced. Although for some of the cases the values don't decrease, this could be because the under-usage of some resources increases a lot and it can cause and increase on the value of the variance. Looking at the values obtained for the over usage of the same resources we can clearly notice that they follow the same trend, which is a very logic fact due to the close relation between the two concepts. The difference between the values for the weekends and the no weekends is also visible and remarkable for all the resources excepting the MC beds; the values for the weekends are smaller.

The most important factors for a hospital in order to be competent are the patient service and hospital efficiency. For that we analyze the impact of our two strategies in the two factors, in the following figures there is represented the results for this two factors for each of the situations described. The value for the patient's satisfaction is influenced by the cancelled patients and the waiting time; while the hospital efficiency is determined with the overuse of the resources and the number of cancelled slots. We assign a certain weight, according to the importance of each and to the scale (hours, days, number of beds, etc.), to each of the factors that influenced and the formulas obtained are:

$$Hospitalefficiency = \frac{1}{250 * cancel\ slots + 250 * OT + 1500 * ICbeds + 50 * NH + 500 * MCbeds}$$

$$Patient\ satisfisfaction = \frac{1}{500 * cancel\ slots + 50 * 28 * wating\ time}$$

The weight given to the cancelation of emergency patients and elective patients is the same. The values of OT, IC beds, NH and MC beds are the overuse of this resources compared to the target level, and the waiting time refers to the average of waiting time calculated previously. In Figure 5 there are the results for situations a, and in Figure 6 for situations b.

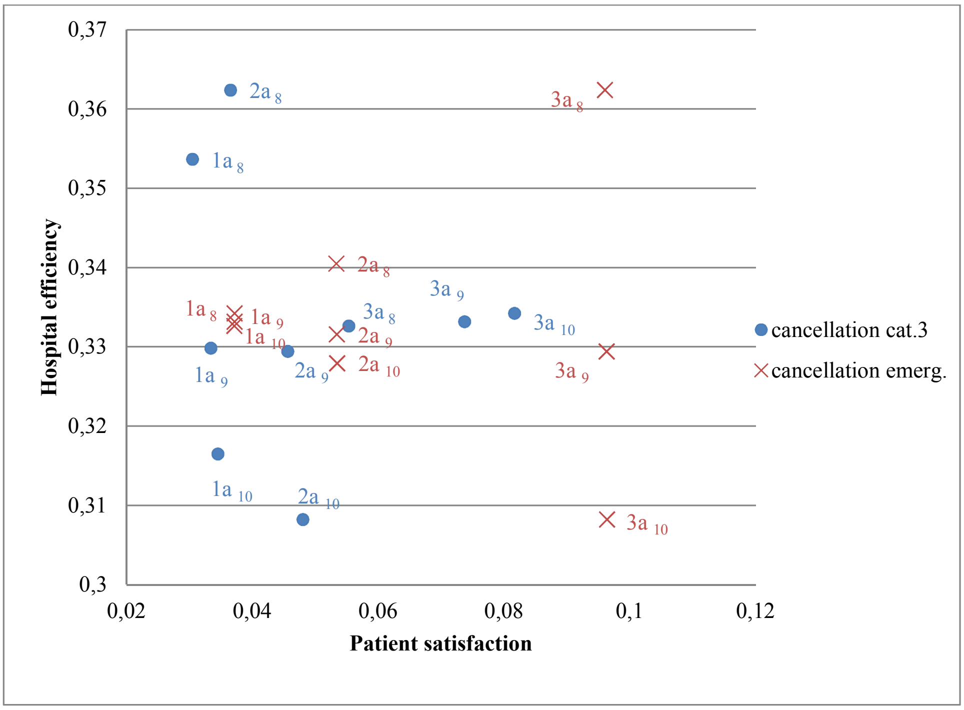

Figure 5: Hospital efficiency and patient satisfaction for situations a

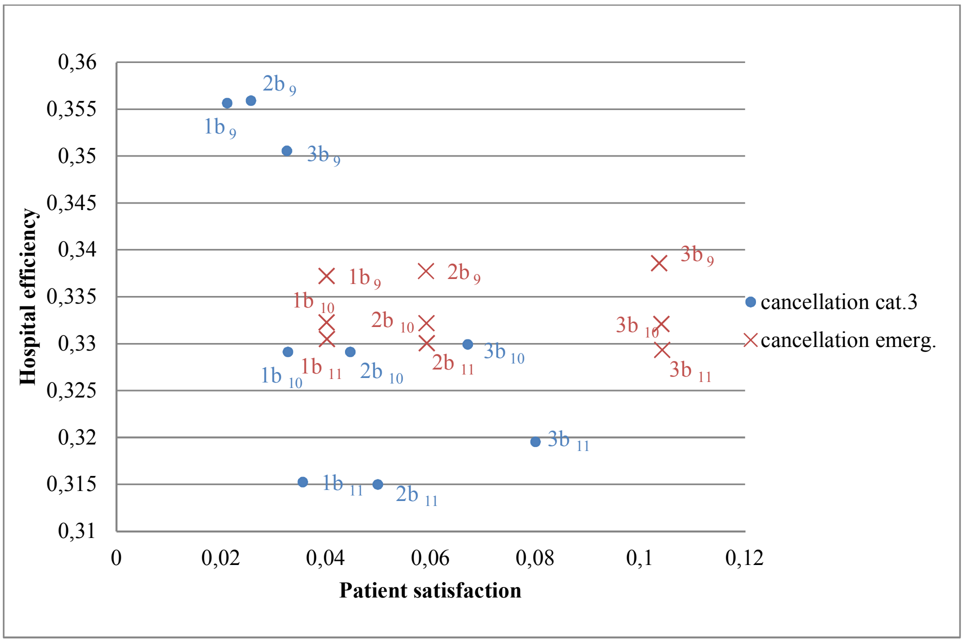

Figure 6: Hospital efficiency and patient satisfaction for situations b

In both figures the trend followed by the values of situation a and b are very similar. For the cancelation of emergency operations strategy, the hospital efficiency increases when the restriction becomes stronger but the patient satisfaction doesn't experience any relevant change, the number of canceled patients with each restriction is almost the same. Although in this factor, patient satisfaction, there is an important change between the different situations. Patient satisfaction for situations 3 is bigger than for the other two situations, the fact of having more slots available reduces the waiting time.

While for the second strategy, cancelation of elective of category 3 operations, the patient satisfaction is reduced when the strength of the restrictions increases, when there are less IC beds. The trend followed for the hospital efficiency is the same as in the other strategy, it increases when the restriction is stronger. In this case we can also notice the difference between each situation in the patient satisfaction, but this difference is smaller than for the other strategy.

Following the figures, the best possible situation would be to apply the cancelation of emergency operations with the strongest restriction. In this way the hospital efficiency increases while the patient satisfaction has no relevant change.

5. CONCLUSION

In this paper, first we derived probability distributions of waiting time computed from tactical plans with the purpose of improving hospital efficiency by optimizing the resources usage. Our models deal with both emergency and elective patients. We used the steady state probabilities of the number of patients for each category in each day to compute the exact levels of resources usage and waiting time computations. After we developed two strategies to improve the usage of the IC bed occupancy: cancellation of operation of emergency patients and cancellation of operation of elective patients of category 3, and we detailed the steps of each procedure.

Both strategies, in general, tend to reduce the over-usage, the expected values and the variance of the critical resources, IC beds, nursing hours, operating time and MC beds. And we can also assert that by making stronger the restriction we reduce these three factor, over-usage, expected values and the variance. When talking about hospital efficiency in both strategies the trend is similar. Reducing the number of IC beds, making the restriction stronger, the hospital efficiency increases. But for the cancelation of elective of category 3, by doing this we provoke a reduction of the patient satisfaction. In the other hand, the other strategy doesn't experience any relevant change in this factor. There is also an important difference, when looking at patient satisfaction, between the different situations. Situation 3 has the best results in this. In general, the best possible situation is with the cancelation of emergency operations and the strongest restriction, less number of IC beds available.

ANEX 1: THE DESCRIPTION OF THE PROGRAM

In this section the detailed description of the program used to provide all the information of the Case Study is written:

```
procedure TForm1.Button8Click(Sender: TObject);
var i,j,k,count,h,m,x,l,t,i1,k2:integer;
    h1,h2,h3,h4,h11,h12,h13,h14,underuse,overuse,capn1,capn2,a:real;
    outfile:textfile;
    {proICnurs:array[1..NC,0..op,0..op,1..maxIC]of real; }
    q:array[1..28,0..100] of real;    {prob to have k patients for type i on day j}
    arr:array[0..op] of real;    {prob to have k arrivals}
    emarr:array[1..7,0..op] of real; {prob to have j arrivals of emergency patients on day k}
    stot:array[1..NC,0..op,1..cycle]of real; {prob to have j operations of type i on day k}
    stotDAY:array[1..NC,0..op,1..cycle]of real;
    {prob to have j operations of tye i on day k durin}
    pot,POT1:array[0..oh,1..cycle] of real;
    plic,plic1,PIC,PIC1:array[0..ic,1..cycle] of real;
    pnh:array[0..NH,1..cycle] of real; {prob to have m nursing hours on day k}
    pnh1:array[0..NH] of real;
    plmc,plmc1,pmc,PMC1:array[0..40,1..cycle] of real;
    {prob de que hayan m pacientes en MC el dia k}
    {proMC:array[1..NC,0..op,0..op,-1..maxMC] of real;}
     infile:textfile;
begin
  assignfile(outfile,'proboutS.dat');
  rewrite(outfile);
  for k:=1 to 7 do
 begin
 h:=0;
 for i:=1 to nc do
 for j:=1 to 4 do
 Mplan[j,i,k]:=0;
 for i:=1 to nc do
  h:=h+Nplan[i,k];
```

```
 if h=0 then
 begin
   for i:=1 to nc do
   Mplan[1,i,k]:=Mplan[1,i,k]+(empatient[k,i]/3);
   for i:=1 to nc do
    for j:=2 to 4 do
   Mplan[j,i,k]:=Mplan[1,i,k]+empatient[k,i];
   end
   else
   begin
   for i:=1 to nc do
   Mplan[1,i,k]:=Mplan[1,i,k]+((lambdapatient[i]/20)+(empatient[k,i]/3));
    for j:=2 to 4 do
    for i:=1 to nc do
   Mplan[j,i,k]:=Mplan[1,i,k]+((lambdapatient[i]/20)+(empatient[k,i]));
   end;
   end;
   for i:=1 to nc do
   for k:=1 to 7 do
writeln(outfile,'Mplan',Mplan[1,i,k]:8:3,Mplan[2,i,k]:8:3,Mplan[3,i,k]:8:3,Mplan[4,i,k]:8:3,lambdapatient[i]:8:3,emp
atient[k,i]:8:3);
   for k:=1 to 7 do
   begin
   TCap[1,k]:=0;
   TCap[2,k]:=0;
   TCap[3,k]:=0;
   TCap[4,k]:=0;
   for i:=1 to nc do
  TCap[1,k]:= Tcap[1,k]+Mplan[1,i,k]*ot[i];
   for i:=1 to nc do
   for l:=1 to maxic do
   TCap[2,k]:=Tcap[2,k]+Mplan[2,i,k]*cumpercIC[i,l];
   for i:=1 to nc do
   for l:=1 to maxic do
```

```
TCap[3,k]:= Tcap[3,k]+Mplan[3,i,k]*nurse[i,l]*cumpercICnurs[i,l];
Tcap[3,k]:=Tcap[3,k]/maxic;
for i:=1 to nc do
 for l:=-1 to maxmc do
 TCap[4,k]:=Tcap[4,k]+Mplan[4,i,k]*cumpercmC[i,l];
 end;
 for k:=8 to 14 do
 begin
 TCap[1,k]:=0;
 TCap[2,k]:=0;
 TCap[3,k]:=0;
 TCap[4,k]:=0;
 for i:=1 to nc do
TCap[1,k]:= Tcap[1,k]+Mplan[1,i,k-7]*ot[i];
 for i:=1 to nc do
 for l:=1 to maxic do
 TCap[2,k]:=Tcap[2,k]+Mplan[2,i,k-7]*cumpercIC[i,l];
 for i:=1 to nc do
 for l:=1 to maxic do
TCap[3,k]:= Tcap[3,k]+Mplan[3,i,k-7]*nurse[i,l]*cumpercICnurs[i,l];
Tcap[3,k]:=Tcap[3,k]/maxic;
for i:=1 to nc do
 for l:=-1 to maxmc do
 TCap[4,k]:=Tcap[4,k]+Mplan[4,i,k-7]*cumpercmC[i,l];
 end;
 for k:=15 to 21 do
 begin
 TCap[1,k]:=0;
 TCap[2,k]:=0;
 TCap[3,k]:=0;
 TCap[4,k]:=0;
 for i:=1 to nc do
TCap[1,k]:= Tcap[1,k]+Mplan[1,i,k-14]*ot[i];
 for i:=1 to nc do
```

```
 for l:=1 to maxic do
 TCap[2,k]:=Tcap[2,k]+Mplan[2,i,k-14]*cumpercIC[i,l];
 for i:=1 to nc do
 for l:=1 to maxic do
TCap[3,k]:= Tcap[3,k]+Mplan[3,i,k-14]*nurse[i,l]*cumpercICnurs[i,l];
Tcap[3,k]:=Tcap[3,k]/maxic;
for i:=1 to nc do
 for l:=-1 to maxmc do
 TCap[4,k]:=Tcap[4,k]+Mplan[4,i,k-14]*cumpercmC[i,l];
 end;
 for k:=22 to 28 do
 begin
 TCap[1,k]:=0;
 TCap[2,k]:=0;
 TCap[3,k]:=0;
 TCap[4,k]:=0;
 for i:=1 to nc do
TCap[1,k]:= Tcap[1,k]+Mplan[1,i,k-21]*ot[i];
 for i:=1 to nc do
 for l:=1 to maxic do
 TCap[2,k]:=Tcap[2,k]+Mplan[2,i,k-21]*cumpercIC[i,l];
 for i:=1 to nc do
 for l:=1 to maxic do
TCap[3,k]:= Tcap[3,k]+Mplan[3,i,k-21]*nurse[i,l]*cumpercICnurs[i,l];
Tcap[3,k]:=Tcap[3,k]/maxic;
for i:=1 to nc do
 for l:=-1 to maxmc do
 TCap[4,k]:=Tcap[4,k]+Mplan[4,i,k-21]*cumpercmC[i,l];
 end;
 for k:=1 to cycle do
 writeln(outfile,'tcap',Tcap[1,k]:8:3,Tcap[2,k]:8:3,Tcap[3,k]:10:3,Tcap[4,k]:8:3);

{Comprobar resultados}
for k:=1 to cycle do
```

```
writeln(outfile,'Tcap',k:4,Tcap[1,k]:8:3,Tcap[2,k]:8:3,Tcap[3,k]:8:3,Tcap[4,k]:8:3);
for i:=1 to NC do
for k:=1 to cycle do
begin
  h1:=Nplan[i,k];
  writeln(outfile,'NPLAN',i:4,k:4,h1:8:3);
end;
for i:=1 to NC do
begin
  h1:=0;
  for j:=-1 to MaxMC do
  h1:=h1+cumpercMC[i,j];
  writeln(outfile,'CumperMC',i:4,j:4,h1);
end;
for i:=1 to NC do
begin
  h1:=0;
  for j:=1 to MaxIC do
  h1:=h1+cumpercIC[i,j];
  writeln(outfile,'CumperIC',i:4,j:4,h1);
end;
for i:=1 to NC do
begin
  h1:=0;
  for j:=1 to MaxIC do
  h1:=h1+cumpercICnurs[i,j];
  writeln(outfile,'CumperICnurs',i:4,j:4,h1);
end;
for i:=1 to NC do
begin
  maxop[i]:=0;
  for k:=1 to cycle do
  begin
    h:=Nplan[i,k];
```

```
    if h>maxop[i] then
    maxop[i]:=h;
  end;
end;
{Leer distribución elective patients, Calculo S}
for i:=1 to NC do
begin
  q[1,0]:=1;
  for j:=1 to 100 do
  q[1,j]:=0;
  arr[0]:=exp(-lambdapatient[i]/cycle);
  for j:=1 to op do
  arr[j]:=arr[j-1]*lambdapatient[i]/(cycle*j);
  if i=3 then
  for j:=0 to 100 do
  writeln(outfile,'arr',arr[j]:8:3);
  for count:=1 to simduur do
  begin
    for k:=2 to cycle do
    begin
      if Nplan[i,k-1]>0 then
      begin   {remove operation scheduled patients}
        h:=Nplan[i,k-1];
        if count=simduur then
        begin
          h1:=1;
          for j:=0 to h-1 do
          begin
            s[i,j,k-1]:=q[k-1,j];
            h1:=h1-q[k-1,j];
          end;
          s[i,h,k-1]:=h1;
          for j:=h+1 to 5 do
          s[i,j,k-1]:=0;
```

```
    end;
    for j:=1 to h do
    q[k-1,0]:=q[k-1,0]+q[k-1,j];
    for j:=1 to 100-h do
    q[k-1,j]:=q[k-1,j+h];
    for j:=100-h+1 to 100 do
    q[k-1,j]:=0;
  end;
  if (count=simduur) and (Nplan[i,k-1]=0)  then
  s[i,0,k-1]:=1;
  for j:=0 to 100 do
  q[k,j]:=q[k-1,j]*arr[0];
  for m:=1 to op do
  for j:=0 to 100-m do
  q[k,j+m]:=q[k,j+m]+q[k-1,j]*arr[m];
  h1:=0;
  for j:=0 to 100 do
  h1:=h1+q[k,j];
  q[k,0]:=q[k,0]+1-h1;
end;
if Nplan[i,cycle]>0 then
begin   {remove operation scheduled patients}
  h:=Nplan[i,cycle];
  if count=simduur then
  begin
    h1:=1;
    for j:=0 to h-1 do
    begin
      s[i,j,cycle]:=q[cycle,j];
      h1:=h1-q[cycle,j];
    end;
    s[i,h,cycle]:=h1;
    for j:=h+1 to 5 do
    s[i,j,cycle]:=0;
```

```
    end;
    for j:=1 to h do
    q[cycle,0]:=q[cycle,0]+q[cycle,j];
    for j:=1 to 100-h do
    q[cycle,j]:=q[cycle,j+h];
    for j:=100-h+1 to 100 do
    q[cycle,j]:=0;
  end;
  if (count=simduur) and (Nplan[i,k-1]=0)  then
  s[i,0,k-1]:=1;
  if count<simduur then
  begin
    for j:=0 to 100 do
    q[1,j]:=q[cycle,j]*arr[0];
    for m:=1 to op do
    for j:=0 to 100-m do
    q[1,j+m]:=q[1,j+m]+q[cycle,j]*arr[m];
    h1:=0;
    for j:=0 to 100 do
    h1:=h1+q[1,j];
    h2:=0;
    for j:=0 to 100 do
    h2:=h2+j*q[1,j];
    q[1,0]:=q[1,0]+1-h1;
  end;
end;    {count=1 to simduur}
h2:=0;
for k:=1 to cycle do
for j:=0 to 100 do
h2:=h2+j*q[k,j];
h1:=h2/28;
if i=3 then we:=h1;
writeln(outfile,'wachtenden',i:4,h1:8:2);
h2:=h2/lambdapatient[i]; {waiting time}
```

```
  if i=3 then wt:=h2;
  writeln(outfile,'waiting time',i:4,h2:8:2);
end;
if (not Noemergencies.Checked) then
begin
  {Calculation of Sem}
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/j);
    end;
    for j:=0 to op do
    begin
      for k:=1 to 7 do
      sem[i,j,k]:=emarr[k,j];
      for k:=8 to 14 do
      sem[i,j,k]:=emarr[k-7,j];
      for k:=15 to 21 do
      sem[i,j,k]:=emarr[k-14,j];
      for k:=22 to cycle do
      sem[i,j,k]:=emarr[k-21,j];
    end;
    {Calculation of maxop[i]}
    for k:=1 to 7 do
    begin
      for j:=0 to op do
      if emarr[k,j]>0.0001 then
      begin
        h:=Nplan[i,k]+j;
        if h>maxop[i] then
        maxop[i]:=h;
```

```
        end;
      end;
  end; {type of patients (i)}
  for i:=1 to nc do
  writeln(outfile,'maxop',i:4,maxop[i]:8);
  {Calculation of Stot}
  capn2:=0;
  for i:=1 to NC do
  begin
    capn1:=0;
    for k:=1 to cycle do
    begin
      for j:=0 to maxop[i] do
      begin
        stot[i,j,k]:=0;
        if j>=Nplan[i,k] then
        begin
          for x:=0 to Nplan[i,k] do
          stot[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
        end;
        if j<Nplan[i,k] then
        begin
          for x:=0 to j do
          stot[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
        end;
        writeln (outfile,'Stot',i:4,j:4,k:4,Stot[i,j,k]:8:3);
        capn1:=capn1+j*Stot[i,j,k];
      end;
    end;
    writeln(outfile,'capn1',capn1:8:2);
    capn2:=capn2+capn1*OT[i];
  end;
  writeln(outfile,'capn2',capn2:8:2);
end {if not Noemergencies}
```

```
else
for i:=1 to Nc do
begin
  capn1:=0;
  for k:=1 to cycle do
  for j:=0 to Nplan[i,k] do
  capn1:=capn1+j*S[i,j,k];
  writeln(outfile,'capn1',capn1:8:2);
end;
{Calculation of StotDAY(only used for OT)}
capn2:=0;
if (not Noemergencies.Checked) then
begin
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]/3);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/(j*3));
    end;
    for j:=0 to op do
    begin
      for k:=1 to 7 do
      sem[i,j,k]:=emarr[k,j];
      for k:=8 to 14 do
      sem[i,j,k]:=emarr[k-7,j];
      for k:=15 to 21 do
      sem[i,j,k]:=emarr[k-14,j];
      for k:=22 to cycle do
      sem[i,j,k]:=emarr[k-21,j];
    end;
  end;
  for i:=1 to NC do
```

```
  begin
    capn1:=0;
    for k:=1 to cycle do
    begin
      h3:=0;
      for j:=0 to maxop[i] do
      begin
        stotDAY[i,j,k]:=0;
        if j>=Nplan[i,k] then
        begin
          for x:=0 to Nplan[i,k] do
          stotDAY[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+StotDAY[i,j,k];
        end;
        if j<Nplan[i,k] then
        begin
          for x:=0 to j do
          stotDAY[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+StotDAY[i,j,k];
        end;
        writeln (outfile,'StotDAY',i:4,j:4,k:4,Stotday[i,j,k]:8:3);
        capn1:=capn1+j*Stotday[i,j,k];
        h3:=h3+j*Stotday[i,j,k];
      end;
      writeln (outfile,'exp op',i:4,k:4,h3:8:3);
    end;
    h3:=lambdapatient[i];
    for j:=1 to 7 do
    h3:=h3+4*empatient[j,i]/3;
    writeln(outfile,'capn1',capn1:8:2,h3:8:2);
    capn2:=capn2+capn1*OT[i];
  end;   {type of patients (i)}
  writeln(outfile,'capn2',capn2:8:2);
end;  {not Noemergencies}
closefile(outfile);
{Calculation of POT}
```

```
assignfile(outfile,'proboutPOT.dat');
rewrite(outfile);
for k:=1 to cycle do
for m:=0 to oh do
pot[m,k]:=0;
for k:=1 to cycle do
begin
  pot[0,k]:=1;
  underuse:=0;
  overuse:=0;
  for i:=1 to NC do
  begin
    if (not Noemergencies.Checked) then
    begin
      for m:=0 to oh do
      pot1[m,k]:=0;
      for j:=0 to maxop[i] do
      if j*ot[i]<=oh then
      for m:=0 to oh-(j*ot[i]) do
      pot1[m+(j*ot[i]),k]:=POT1[m+(j*ot[i]),k]+POT[m,k]*StotDAY[i,j,k];
    end {not Noemergencies }
    else
    begin
      for m:=0 to oh do
      pot1[m,k]:=0;
      for j:=0 to Nplan[i,k] do
      for m:=0 to oh-(Nplan[i,k]*ot[i]) do
      pot1[m+(j*ot[i]),k]:=POT1[m+(j*ot[i]),k]+POT[m,k]*S[i,j,k];
    end; { Noemergencies}
    for m:=0 to oh do
    pot[m,k]:=POT1[m,k];
    h3:=0;
    for m:=0 to oh do
    h3:=h3+m*pot[m,k];
```

```
    writeln(outfile,'ot,day,cat',k:4,i:4,h3:8:2);
  end; {type of patients (i)}
  writeln(outfile,'ot-day',k:4);
  h1:=0;
  for m:=0 to oh do
  begin
    writeln(outfile,m:4,POT[m,k]:8:3);
    h1:=h1+POT[m,k]*m;
    if k=cycle then
    h2:=Tcap[1,1] else
    h2:=Tcap[1,k+1];
    if m<h2 then
    underuse:=underuse+(h2-m)*POT[m,k]
    else
    overuse:=overuse-(h2-m)*POT[m,k];
  end;
  writeln(outfile,'average OT,underuse,overuse', h1:8:3,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
{Calculation for the IC beds}
assignfile(outfile,'proboutPIC.dat');
rewrite(outfile);
for k:=1 to cycle do
for i:=1 to ic do
pic[i,k]:=0;
for k:=1 to cycle do
pic[0,k]:=1;
for i:=1 to NC do
for j:=1 to op do
for k:=1 to maxIC do
for m:=0 to j do
proIC[i,j,m,k]:=0;
for i:=1 to NC do
begin
```

```
for j:=1 to op do      {calculate prob that patients are still in IC}
for k:=1 to maxIC do
begin
  h1:=1;
  h2:=cumpercIC[i,k];
  if h2=0 then
  proIC[i,j,0,k]:=1
  else
  begin
    for m:=1 to j do
    h1:=h1*h2;
    proIC[i,j,j,k]:=h1;
    writeln(outfile,'proic', i:4,j:4,j:4,k:4, ProIC[i,j,j,k]:8:3);
    for m:=j-1 downto 0 do
    begin
      h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
      proIC[i,j,m,k]:=h1;
      writeln(outfile,'proic', i:4,j:4,m:4,k:4, ProIC[i,j,m,k]:8:3);
    end;
  end;
end;
for k:=1 to cycle do
begin
  plic[0,k]:=1;
  for m:=1 to ic do
  plic[m,k]:=0;
end;
for t:=1 to cycle do
begin
  if (not Noemergencies.Checked) then
  for l:=1 to maxIC do
  begin
    k2:=1+((t+l-1)mod cycle);
    h1:=0;
```

```
  for m:=0 to ic do
  begin
    plic1[m,k2]:=Plic[m,k2];
    h1:=h1+plic[m,k2];
    plic[m,k2]:=0;
  end;
  for k:=0 to op do
  begin
    for j:=0 to k do
    begin
      if k=0 then
      h1:=Stot[i,k,t] else
      h1:=Stot[i,k,t]*ProIC[i,k,j,l];
      if (h1>0) and (h1<1) then
      for i1:=ic-j downto 0 do
      plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
    end;
  end;
end
else
if Nplan[i,t]>0 then
for l:=1 to maxIC do
begin
  k2:=1+((t+l-1)mod cycle);
  h1:=0;
  for m:=0 to ic do
  begin
    plic1[m,k2]:=Plic[m,k2];
    h1:=h1+plic[m,k2];
    plic[m,k2]:=0;
  end;
  for k:=0 to op do
  for j:=0 to k do
  begin
```

```
            if k=0 then
            h1:=S[i,k,t] else
            h1:=S[i,k,t]*ProIC[i,k,j,l];
            if (h1>0) and (h1<1) then
            for i1:=ic-j downto 0 do
            plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
          end;
        end;
      end;
      for k:=1 to cycle do
      begin
        for m:=0 to ic do
        pic1[m,k]:=0;
        for j:=0 to ic do
        for m:=0 to ic-j do
        pic1[m+j,k]:= PIC1[m+j,k]+PIC[m,k]*Plic[j,k];
        for m:=0 to ic do
        pic[m,k]:=PIC1[m,k];
        h1:=0;
        for m:=0 to ic do
        h1:=h1+pic[m,k];
        writeln(outfile,'totkans',h1:8:3);
      end;
      for k:=1 to cycle do
      begin
        h1:=0;
        for m:=0 to ic do
        begin
          h1:=h1+PIC[m,k];
          writeln(outfile,'PIC',i:4,m:4,k:4,h1:8:3,PIC[m,k]:8:3)
        end;
      end;
    end;
    for k:=1 to cycle do
```

```
begin
  h1:=0;
  h2:=Tcap[2,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to ic do
  begin
    h1:=h1+m*PIC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PIC[m,k]
    else
    overuse:=overuse-(h2-m)*PIC[m,k];
  end;
  writeln(outfile,'EIC,underuse,overuse', h1:8:3,Tcap[2,k]:8:2,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
{Calculation of nursing hours for each day k}
assignfile(outfile,'proboutPNH.dat');
rewrite(outfile);
for k:=1 to cycle do
begin
  for m:=0 to NH do
  pnh[m,k]:=0;
end;
for i:=1 to NC do
for j:=1 to op do
for k:=1 to maxIC do
for m:=0 to j do
proICnurs[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do     {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
```

```
    if Nurse[i,k]=0 then
    h2:=0
    else
    begin
      h1:=1;
      h2:=cumpercICnurs[i,k]/Nurse[i,k];
    end;
    if h2=0 then
    proICnurs[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proICnurs[i,j,j,k]:=h1;
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proICnurs[i,j,m,k]:=h1;
      end;
    end;
  end;
end;
for k:=1 to cycle do
begin
  pnh[0,k]:=1;
  for j:=1 to NH do
  pnh[j,k]:=0;
  for i:=1 to NC do
  begin
    for l:=1 to maxIC do
    begin
      if (not Noemergencies.Checked) then
      begin
        for m:=0 to NH do
```

```
  pnh1[m]:=0;
  for h:=0 to maxop[i] do
  begin
    k2:=k-l;
    if k2<1 then k2:=k2+cycle;
    for j:=0 to h do
    begin
      if h=0 then
      h1:=Stot[i,h,k2] else
      h1:=Stot[i,h,k2]*proICnurs[i,h,j,l];
      if j*Nurse[i,l]<=NH then
      begin
        for m:=0 to NH-(Nurse[i,l]*j) do
        pnh1[m+(j*Nurse[i,l])]:= PNH1[m+(Nurse[i,l]*j)]+PNH[m,k]*h1;
      end;
    end;
  end;
end
else
begin
  for m:=0 to NH do
  pnh1[m]:=0;
  k2:=k-l;
  if k2<1 then k2:=k2+cycle;
  for h:=0 to Nplan[i,k2] do
  begin
    for j:=0 to h do
    begin
      if h=0 then
      h1:=S[i,h,k2] else
      h1:=S[i,h,k2]*proICnurs[i,h,j,l];
      for m:=0 to NH-(Nurse[i,l]*Nplan[i,k2]) do
      pnh1[m+(j*Nurse[i,l])]:=PNH1[m+(Nurse[i,l]*j)]+PNH[m,k]*h1;
    end;
```

```
        end;
      end;
      for m:=0 to NH do
      pnh[m,k]:=PNH1[m];
    end;
  end;
  writeln(outfile,'nh-day',k:4);
  for m:=0 to NH do
  writeln(outfile,m:4,PNH[m,k]:8:3);
end;
for k:=1 to cycle do
begin
  h1:=0;
  h2:=Tcap[3,k];
  underuse:=0;
  overuse:=0;
  for m:=0 to NH do
  begin
    h1:=h1+m*PNH[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PNH[m,k]
    else
    overuse:=overuse-(h2-m)*PNH[m,k];
  end;
  writeln(outfile,'ENH,underuse,overuse',h1:8:3,Tcap[3,k]:8:3,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
{Calculation of MC beds}
assignfile(outfile,'proboutPMC.dat');
rewrite(outfile);
for k:=1 to cycle do
for i:=1 to 40 do
pmc[i,k]:=0;
for k:=1 to cycle do
```

```
pmc[0,k]:=1;
for i:=1 to NC do
for j:=1 to op do
for k:=-1 to maxMC do
for m:=0 to j do
proMC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do
  begin
    for k:=-1 to maxMC do
    begin
      h1:=1;
      h2:=cumpercMC[i,k];
      if h2=0 then
      proMC[i,j,0,k]:=1
      else
      begin
        for m:=1 to j do
        h1:=h1*h2;
        proMC[i,j,j,k]:=h1;
        writeln(outfile,'proMC',i:4,j:4,j:4,k:4,proMC[i,j,j,k]:8:3);
        for m:=j-1 downto 0 do
        begin
          h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
          proMC[i,j,m,k]:=h1;
          writeln(outfile,'proMC',i:4,j:4,m:4,k:4,proMC[i,j,m,k]:8:3);
        end;
      end;
    end;
  end;
  for k:=1 to cycle do
  begin
    plmc[0,k]:=1;
```

```
  for m:=1 to 40 do
  plmc[m,k]:=0;
end;
for t:=1 to cycle do
begin
  if (not Noemergencies.Checked) then
  for l:=-1 to maxMC do
  begin
    if l=-1 then
    begin
      if t=1 then k2:=1+((t+l+cycle-1)mod cycle)
      else
      k2:=1+((t+l-1)mod cycle);
    end;
    if (l<=cycle) and (l>=0) then
    k2:=1+((t+l-1)mod cycle);
    if l>cycle then  {maxMC>cycle, prob that we have patients
    from the previous cycle on they k of the new cycle}
    k2:=1+((t+l-cycle-1)mod cycle);
    h1:=0;
    for m:=0 to 40 do
    begin
      plmc1[m,k2]:=Plmc[m,k2];
      h1:=h1+plmc[m,k2];
      plmc[m,k2]:=0;
    end;
    for k:=0 to op do
    for j:=0 to k do
    begin
      if k=0 then
      h1:=Stot[i,k,t] else
      h1:=Stot[i,k,t]*proMC[i,k,j,l];
      if (h1>0) and (h1<1) then
      for i1:=40-j downto 0 do
```

```
    plmc[i1+j,k2]:=Plmc[i1+j,k2]+Plmc1[i1,k2]*h1;
  end;
end
else
if Nplan[i,t]>0 then
for l:=-1 to maxMC do
begin
  if l=-1 then
  begin
    if t=1 then k2:=1+((t+l+cycle-1)mod cycle)
    else
    k2:=1+((t+l-1)mod cycle);
  end;
  if (l<=cycle) and (l>=0) then
  k2:=1+((t+l-1)mod cycle);
  if l>cycle then  {maxMC>cycle, prob that we have patients
  from the previous cycle on they k of the new cycle}
  k2:=1+((t+l-cycle-1)mod cycle);
  h1:=0;
  for m:=0 to 40 do
  begin
    plmc1[m,k2]:=Plmc[m,k2];
    h1:=h1+plmc[m,k2];
    plmc[m,k2]:=0;
  end;
  for k:=0 to op do
  for j:=0 to k do
  begin
    if k=0 then
    h1:=S[i,k,t] else
    h1:=S[i,k,t]*proMC[i,k,j,l];
    if (h1>0) and (h1<1) then
    for i1:=40-j downto 0 do
    plmc[i1+j,k2]:=Plmc[i1+j,k2]+Plmc1[i1,k2]*h1;
```

```
        end;
      end;
    end;
    for k:=1 to cycle do
    begin
      for j:=0 to 40 do
      writeln(outfile,i:4,k:4,Nplan[i,k]:4,Plmc[j,k]:8:3);
      for m:=0 to 40 do
      pmc1[m,k]:=0;
      for j:=0 to 40 do
      for m:=0 to 40-j do
      pmc1[m+j,k]:=PMC1[m+j,k]+PMC[m,k]*plmc[j,k];
      for m:=0 to 40 do
      pmc[m,k]:=PMC1[m,k];
      h1:=0;
      for m:=0 to 40 do
      h1:=h1+PMC[m,k];
      writeln(outfile,'totkans',h1:8:3);
    end;
    for k:=1 to cycle do
    begin
      h1:=0;
      for m:=1 to 40 do
      begin
        h1:=h1+PMC[m,k];
        writeln(outfile,'PMC',i:4,m:4,k:4,h1:8:3,PMC[m,k]:8:3);
      end;
    end;
  end; {tipo de pacientes (i)}
  for k:=1 to cycle do
  begin
    h1:=0;
    h2:=Tcap[4,k];
    underuse:=0;
```

```
    overuse:=0;
    for m:=1 to 40 do
    begin
      h1:=h1+m*PMC[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PMC[m,k]
      else
      overuse:=overuse-(h2-m)*PMC[m,k];
    end;
    writeln(outfile,'EMC,underuse,overuse', h1:8:3,Tcap[4,k]:8:2,underuse:8:3,overuse:8:3);
  end;
  closefile(outfile);
  {Write the file with all the results}
  assignfile(outfile,'proboutfinal.dat');
  rewrite(outfile);
  h3:=0;
  h4:=0;
  for k:=1 to cycle do
  begin
    h1:=0;
    h11:=0;
    overuse:=0;
    underuse:=0;
    for m:=0 to oh do
    begin
      h1:=h1+POT[m,k]*m;
      h11:=h11+POT[m,k]*m*m;
      if k=cycle then
      h2:=Tcap[1,1] else
      h2:=Tcap[1,k+1];
      if m<h2 then
      underuse:=underuse+(h2-m)*POT[m,k]
      else
      overuse:=overuse-(h2-m)*POT[m,k];
```

```
   end;
   h14:=h11-(h1*h1);
   writeln(outfile,'day',k:4,'  average OT,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
  h:=h+Nplan[i,k];
 if h=0 then
 begin
 for m:=0 to oh do
 begin
 h1:=h1+1;
 h2:=h2+(m*POT[m,k]);
 end;
 end
 else
 for m:=0 to oh do
 begin
 h11:=h11+1;
 h12:=h12+(m*POT[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
```

```
 writeln(outfile,'media POT (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
   h1:=0;
   h11:=0;
   h2:=Tcap[2,k];
   underuse:=0;
   overuse:=0;
   for m:=0 to ic do
   begin
      h1:=h1+m*PIC[m,k];
      h11:=h11+m*m*PIC[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PIC[m,k]
      else
      overuse:=overuse-(h2-m)*PIC[m,k];
   end;
   h14:=h11-(h1*h1);
   writeln(outfile,'day',k:4,'  average IC,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
```

```
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
 begin
 for m:=0 to ic do
 begin
 h1:=h1+1;
 h2:=h2+(m*PIC[m,k]);
 end;
 end
 else
 for m:=0 to ic do
 begin
 h11:=h11+1;
 h12:=h12+(m*PIC[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PIC (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
   h1:=0;
   h11:=0;
   h2:=Tcap[3,k];
   underuse:=0;
   overuse:=0;
   for m:=0 to NH do
   begin
      h1:=h1+m*PNH[m,k];
      h11:=h11+m*m*PNH[m,k];
```

```
    if m<h2 then
    underuse:=underuse+(h2-m)*PNH[m,k]
    else
    overuse:=overuse-(h2-m)*PNH[m,k];
  end;
  h14:=h11-(h1*h1);
  writeln(outfile,'day',k:4,'  average NH,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
  h3:=h3+underuse;
  h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
 begin
 for m:=0 to NH do
 begin
 h1:=h1+1;
 h2:=h2+(m*PNH[m,k]);
 end;
 end
 else
 for m:=0 to NH do
 begin
```

```
 h11:=h11+1;
 h12:=h12+(m*PNH[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PNH (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
  h1:=0;
  h11:=0;
  h2:=Tcap[4,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to 40 do
  begin
    h1:=h1+m*PMC[m,k];
    h11:=h11+m*m*PMC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PMC[m,k]
    else
    overuse:=overuse-(h2-m)*PMC[m,k];
  end;
  h14:=h11-(h1*h1);
  writeln(outfile,'day',k:4,'  average MC,variance,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
  h3:=h3+underuse;
  h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
```

```
  h11:=0;
  h12:=0;
  for k:=1 to cycle do
   begin
   h:=0;
   for i:=1 to NC do
   if k=1 then h:=h+NPlan[i,cycle]
   else
    h:=h+Nplan[i,k-1];
   if h=0 then
   begin
   for m:=0 to 40 do
   begin
   h1:=h1+(m*m*PMC[m,k]);
   h2:=h2+(m*PMC[m,k]);
   end;
   end
   else
   for m:=0 to 40 do
   begin
   h11:=h11+(m*m*PMC[m,k]);
   h12:=h12+(m*PMC[m,k]);
   end;
   end;
  closefile(outfile);
  button8.Caption:='Done';
end;
procedure tform1.Button9Click(Sender: TObject);  {cancellation of some emergencies}
var
     i,j,k,r,count,h,m,x,l,t,i1,k2:integer;
     h1,h2,a:real;
     outfile:textfile;
     maxopem:array[1..NC] of integer;
     plic,plic1,PICel,PIC1el,picem,pic1em,pic,pic1:array[0..ic,1..cycle] of real;
```

```
    pbedocup:array[1..NC,0..ic,1..cycle] of real;
    ppacpermtot,Ppacpermtot1:array[0..ic,1..cycle] of real;
    emarr:array[1..7,0..op] of real;
    pcancemerg:array[1..nc,0..op,1..cycle] of real;


begin
  assignfile(outfile,'resultscancelem.dat');
  rewrite(outfile);
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/j);
    end;
  end;
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/j);
    end;
    for j:=0 to op do
    begin
      for k:=1 to 7 do
      sem[i,j,k]:=emarr[k,j];
      for k:=8 to 14 do
      sem[i,j,k]:=emarr[k-7,j];
      for k:=15 to 21 do
      sem[i,j,k]:=emarr[k-14,j];
```

```
    for k:=22 to cycle do
    sem[i,j,k]:=emarr[k-21,j];
  end;
end;
{Definition of maxop without emergencies}
for i:=1 to NC do
writeln(outfile,'maxop',i:4,maxop[i]:8);
{Calculation of maxopEM[i]}
for i:=1 to NC do
begin
  maxopem[i]:=0;
  for k:=1 to 7 do
  begin
    for j:=0 to op do
    if emarr[k,j]>0.0001 then
    begin
      h:=j;
      if h>maxopem[i] then
      maxopem[i]:=h;
    end;
  end;
end; {type of patients (i)}
for i:=1 to NC do
writeln(outfile,'maxopem',i:4,maxopem[i]:8);
{Calculation of prob of ICbeds without emergencies}
for k:=1 to cycle do
for i:=1 to ic do
picel[i,k]:=0;
for k:=1 to cycle do
picel[0,k]:=1;
for i:=1 to NC do
for j:=1 to maxop[i] do
for k:=1 to maxIC do
for m:=0 to j do
```

```
proIC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to maxop[i] do      {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
    h1:=1;
    h2:=cumpercIC[i,k];
    if h2=0 then
    proIC[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proIC[i,j,j,k]:=h1;
      // writeln(outfile,'proic', i:4,j:4,j:4,k:4, ProIC[i,j,j,k]:8:3);
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proIC[i,j,m,k]:=h1;
        //writeln(outfile,'proic', i:4,j:4,m:4,k:4, ProIC[i,j,m,k]:8:3);
      end;
    end;
  end;  {end of the bucle for k}
  for k:=1 to cycle do
  begin
    plic[0,k]:=1;
    for m:=1 to ic do
    plic[m,k]:=0;
  end;
  for t:=1 to cycle do
  if Nplan[i,t]>0 then
  begin
    for l:=1 to maxIC do
```

```
  begin
    k2:=1+((t+l-1)mod cycle);
    h1:=0;
    for m:=0 to ic do
    begin
      plic1[m,k2]:=Plic[m,k2];
      h1:=h1+plic[m,k2];
      plic[m,k2]:=0;
    end;
    for k:=0 to Nplan[i,t] do
    for j:=0 to k do
    begin
      if k=0 then
      h1:=S[i,k,t] else
      h1:=S[i,k,t]*ProIC[i,k,j,l];
      if (h1>0) and (h1<1) then
      for i1:=ic-j downto 0 do
      plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
    end;
  end;
end;  {end of cycle for t}
for k:=1 to cycle do
begin
  for m:=0 to ic do
  pic1el[m,k]:=0;
  for j:=0 to ic do
  for m:=0 to ic-j do
  pic1el[m+j,k]:= PIC1el[m+j,k]+PICel[m,k]*Plic[j,k];
  for m:=0 to ic do
  picel[m,k]:=PIC1el[m,k];
  h1:=0;
  for m:=0 to ic do
  h1:=h1+picel[m,k];
  // writeln(outfile,'totkans',h1:8:3);
```

```
    end;
    for k:=1 to cycle do
    begin
      h1:=0;
      for m:=1 to ic do
      h1:=h1+PICel[m,k];
      //writeln(outfile,'PICelectives',i:4,k:4,h1:8:3,PICel[0,k]:8:3,
      // PICel[1,k]:8:3,PICel[2,k]:8:3,PICel[3,k]:8:3)
    end;
  end; {end of type of patients}
  for count:=1 to simduurcanc do
  begin
    if count=1 then
    for k:=1 to cycle do
    for j:=0 to ic do
    for i:=1 to NC do
    sem1[i,j,k]:=0;
    for k:=1 to cycle do
    begin
      for i:=1 to NC do
      begin
        ppacpermtot[0,k]:=1;
        for m:=1 to ic do
        ppacpermtot[m,k]:=0;
        for l:=1 to maxIC do
        begin
          k2:=1+((k+l-1)mod cycle);
          h1:=0;
          for j:=0 to ic do
          begin
            ppacpermtot1[j,k2]:=Ppacpermtot[j,k2];
            h1:=h1+Ppacpermtot[j,k2];
            ppacpermtot[j,k2]:=0;
          end; {para las camas ocupadas j}
```

```
  for j:=0 to ic do
  for x:=0 to j do
  begin
    if j=0 then h1:=Sem1[i,j,k]
    else
    h1:=Sem1[i,j,k]*proIC[i,j,x,l];
    if (h1>0) and (h1<1) then
    for i1:=ic-x downto 0 do
    ppacpermtot[i1+j,k2]:=Ppacpermtot[i1+j,k2]+Ppacpermtot1[i1,k2]*h1;
  end; {numero de camas ocupadas j y x}
end; {para los dias en IC l}
for j:=0 to ic do
pbedocup[i,j,k]:=0;
if i=1 then
begin
  if (k=1) and (count=1) then
  for j:=0 to ic do
  pbedocup[1,j,1]:=PICel[j,1]
  else
  for j:=0 to ic do
  for x:=0 to j do
  pbedocup[1,j,k]:=PICel[j-x,k]*Ppacpermtot[x,k]+Pbedocup[1,j,k];
end;{primer tipo de pacientes i=1}
if i>1 then
for j:=0 to ic do
for x:=0 to j do
pbedocup[i,j,k]:=Pbedocup[i-1,j-x,k]*Sem1[i-1,x,k]+Pbedocup[i,j,k];
for j:=0 to ic do
sem1[i,j,k]:=0;
for x:=0 to op do
for j:=0 to ic do
if x+j<=icbed then Sem1[i,x,k]:=Sem1[i,x,k]+Sem[i,x,k]*Pbedocup[i,j,k]
else
if j<icbed then Sem1[i,icbed-j,k]:=Sem1[i,icbed-j,k]+Sem[i,x,k]*Pbedocup[i,j,k]
```

```
        else
        sem1[i,0,k]:=Sem1[i,0,k]+Sem[i,x,k]*Pbedocup[i,j,k];
        for j:=icbed+1 to ic do
        sem1[i,j,k]:=0;
      end;{tipo de pacientes i}
  end;{dias del ciclo k}
end; {contador hasta simduurcanc}
for k:=1 to cycle do
for i:=1 to NC do
for j:=0 to icbed do
writeln(outfile,'k, i, j, NewSem, Pbedocup', k:4,i:4,j:4,Sem1[i,j,k]:8:3,
sem[i,j,k]:8:3,Pbedocup[i,j,k]:8:3);
for i:=1 to nc do
for k:=1 to cycle do
begin
  pcancemerg[i,0,k]:=0;
  for j:=0 to op do
  pcancemerg[i,0,k]:=Pcancemerg[i,0,k]-j*(Sem1[i,j,k]-Sem[i,J,k]);
end;
for i:=1 to nc do
for k:=1 to cycle do
writeln(outfile,'k,j,Pcancemerg', k:4,Pcancemerg[i,0,k]:8:3);
H2:=0;
for i:=1 to nc do
begin
h1:=0;
for k:=1 to cycle do
begin
h2:=h2+pcancemerg[i,0,k];
h1:=h1+pcancemerg[i,0,k];
writeln(outfile,'pactotcanc dia cat', i:4, k:4, pcancemerg[i,0,k]:8:3);
end;
writeln(outfile,'pactotcanc cat', i:4, h1:8:3);
end;
```

```
 writeln(outfile,'pactotcanc TOt', h2:8:3);
 closefile(outfile);  {CANCELLATION OF EMERGENCIES ARRIVALS, CALCULATION OF NEW Sem}
 button9.Caption:='Done';
end;
procedure TForm1.Button10Click(Sender: TObject);  {cancellation of some emergencies}
var
    i,j,k,r,k2,count,h,m,x,l,t,i1:integer;
    h1,h2,h3,h4,h11,h12,h13,h14,v,v1,underuse,overuse,capn1,capn2,a:real;
    outfile:textfile;
    stot,StotDAY,Sem11:array[1..NC,0..ic,1..cycle]of real;
    {prob to have j operations of type i on day k}
    plic,plic1,pic,pic1:array[0..ic,1..cycle] of real;
    pnh:array[0..NH,1..cycle] of real; {prob to have m nursing hours on day k}
    pnh1:array[0..NH] of real;
    plmc,plmc1,pmc,PMC1:array[0..40,1..cycle] of real;
    {prob de que hayan m pacientes en MC el dia k}
    pot,POT1:array[0..oh,1..cycle] of real;
    fact:array[0..op,0..op] of real; {funcion factorial}
    {CALCULATION OF THE NEW Stot}
begin
 assignfile(outfile,'emergeciescancStot.dat');
 rewrite(outfile);
 capn2:=0;
 for i:=1 to NC do
 begin
   capn1:=0;
   for k:=1 to cycle do
   begin
     for j:=0 to maxop[i] do
     begin
       stot[i,j,k]:=0;
       if j>=Nplan[i,k] then
       begin
         for x:=0 to Nplan[i,k] do
```

```
        stot[i,j,k]:=Sem1[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
      end;
      if j<Nplan[i,k] then
      begin
        for x:=0 to j do
        stot[i,j,k]:=Sem1[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
      end;
      writeln (outfile,'Stot',i:4,j:4,k:4,Stot[i,j,k]:8:3);
      capn1:=capn1+j*Stot[i,j,k];
    end;
  end;
  writeln(outfile,'capn1',capn1:8:2);
  capn2:=capn2+capn1*OT[i];
end;
writeln(outfile,'capn2',capn2:8:2);
closefile(outfile);
{CALCULATION OF THE OT HOURS}
assignfile(outfile,'emergenciescancPOT.dat');
rewrite(outfile);
{--------------- calculation of the new StotDAY-----------------}
for x:=0 to op do
begin
  h1:=1;
  for h:=1 to x do
  h1:=h1*h;
  for j:=0 to op do
  begin
    h2:=1;
    for h:=1 to j do
    h2:=h2*h;
    m:=x-j;
    h3:=1;
    for h:=1 to m do
    h3:=h3*h;
```

```
      if j=0 then fact[x,0]:=1
      else
      begin
        if j<x then fact[x,j]:=h1/(h2+h3);
        if j=x then fact[x,j]:=1;
      end;{loop if j is not 0}
    end; {loop for j}
end;{loop for x}
for i:=1 to nc do
begin
    for k:=1 to cycle do
    for j:=0 to op do
    sem11[i,j,k]:=0;
    for k:=1 to cycle do
    for x:=0 to op do
    for j:=0 to x do
    begin
      m:=x-j;
      h1:=1;
      h2:=1;
      for h:=1 to m do
      h1:=h1*(2/3);
      for m:=1 to j do
      h2:=h2*(1/3);
      sem11[i,j,k]:=Sem11[i,j,k]+Sem1[i,x,k]*h1*h2*fact[x,j];
    end;{loop for j}
end;{tipo de pacientes i}
for i:=1 to NC do
begin
    for k:=1 to cycle do
    begin
      for j:=0 to maxop[i] do
      begin
        stotDAY[i,j,k]:=0;
```

```
        if j>=Nplan[i,k] then
        begin
          for x:=0 to Nplan[i,k] do
          stotDAY[i,j,k]:=Sem11[i,j-x,k]*S[i,x,k]+StotDAY[i,j,k];
        end;
        if j<Nplan[i,k] then
        begin
          for x:=0 to j do
          stotDAY[i,j,k]:=Sem11[i,j-x,k]*S[i,x,k]+StotDAY[i,j,k];
        end;
        writeln (outfile,'StotDAY',i:4,j:4,k:4,StotDAY[i,j,k]:8:3,Sem11[i,j,k]:8:3);
      end; {para el numero de operaciones realizadas j}
    end;{para los dias del ciclo en que se realiza k}
end; {para el tipo de pacientes i}
{----------------- end of StotDAY-----------------------------}
for k:=1 to cycle do
for m:=0 to oh do
pot[m,k]:=0;
for k:=1 to cycle do
begin
  pot[0,k]:=1;
  for i:=1 to NC do
  begin
    for m:=0 to oh do
    pot1[m,k]:=0;
    for j:=0 to maxop[i] do
    if j*ot[i]<=oh then
    for m:=0 to oh-(j*ot[i]) do
    pot1[m+(j*ot[i]),k]:=POT1[m+(j*ot[i]),k]+POT[m,k]*StotDAY[i,j,k];
    for m:=0 to oh do
    pot[m,k]:=POT1[m,k];
  end; {type of patients (i)}
  writeln(outfile,'ot-day',k:4);
  for m:=0 to oh do
```

```
  writeln(outfile,m:4,POT[m,k]:8:3);
end; {dia del ciclo k}
for k:=1 to cycle do
begin
  underuse:=0;
  overuse:=0;
  h1:=0;
  for m:=0 to oh do
  begin
    h1:=h1+POT[m,k]*m;
    if k=cycle then
    h2:=Tcap[1,1] else
    h2:=Tcap[1,k+1];
    if m<h2 then
    underuse:=underuse+(h2-m)*POT[m,k]
    else
    overuse:=overuse-(h2-m)*POT[m,k];
  end;{numero de horas operando m}
  writeln(outfile,'average OT,underuse,overuse', h1:8:3,underuse:8:3,overuse:8:3);
end;{dia del ciclo k}
closefile(outfile);
{CALCULATION OF THE IC BEDS}
assignfile(outfile,'emergenciescancPIC.dat');
rewrite(outfile);
for i:=1 to NC do
for j:=1 to op do
for k:=1 to maxIC do
for m:=0 to j do
proIC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do      {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
```

```
    h1:=1;
    h2:=cumpercIC[i,k];
    if h2=0 then
    proIC[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proIC[i,j,j,k]:=h1;
      //writeln(outfile,'proic', i:4,j:4,j:4,k:4, ProIC[i,j,j,k]:8:3);
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proIC[i,j,m,k]:=h1;
        // writeln(outfile,'proic', i:4,j:4,m:4,k:4, ProIC[i,j,m,k]:8:3);
      end;
    end;
  end;
end;
for k:=1 to cycle do
begin
  pic[0,k]:=1;
  for m:=1 to ic do
  pic[m,k]:=0;
end;
for i:=1 to nc do
begin
  for k:=1 to cycle do
  begin
    plic[0,k]:=1;
    for m:=1 to ic do
    plic[m,k]:=0;
  end;
  for t:=1 to cycle do
```

```
for l:=1 to maxIC do
begin
   k2:=1+((t+l-1)mod cycle);
   h1:=0;
   for m:=0 to ic do
   begin
      plic1[m,k2]:=Plic[m,k2];
      h1:=h1+plic[m,k2];
      plic[m,k2]:=0;
   end;
   for k:=0 to op do
   begin
      for j:=0 to k do
      begin
         if k=0 then
         h1:=Stot[i,k,t] else
         h1:=Stot[i,k,t]*ProIC[i,k,j,l];
         if (h1>0) and (h1<1) then
         for i1:=ic-j downto 0 do
         plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
      end;
   end;
end;
for k:=1 to cycle do
begin
   for m:=0 to ic do
   pic1[m,k]:=0;
   for j:=0 to ic do
   for m:=0 to ic-j do
   pic1[m+j,k]:= PIC1[m+j,k]+PIC[m,k]*Plic[j,k];
   for m:=0 to ic do
   pic[m,k]:=PIC1[m,k];
   h1:=0;
   for m:=0 to ic do
```

```
    h1:=h1+pic[m,k];
    // writeln(outfile,'totkans',h1:8:3);
  end;
  for k:=1 to cycle do
  for m:=0 to ic do
  writeln(outfile,'PIC',i:4,m:4,k:4,PIC[m,k]:8:3)
end; {type of patients i}
for k:=1 to cycle do
begin
  h1:=0;
  h2:=Tcap[2,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to ic do
  begin
    h1:=h1+m*PIC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PIC[m,k]
    else
    overuse:=overuse-(h2-m)*PIC[m,k];
  end;
  writeln(outfile,'EIC,underuse,overuse', h1:8:3,Tcap[2,k]:8:2,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
{CALCULATION OF THE NH}
assignfile(outfile,'emergenciescancPNH.dat');
rewrite(outfile);
for i:=1 to NC do
for j:=1 to ic do
for k:=1 to maxIC do
for m:=0 to j do
proICnurs[i,j,m,k]:=0;
for i:=1 to NC do
begin
```

```
  for j:=1 to ic do     {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
    if Nurse[i,k]=0 then
    h2:=0
    else
    begin
      h1:=1;
      h2:=cumpercICnurs[i,k]/Nurse[i,k];
    end;
    if h2=0 then
    proICnurs[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proICnurs[i,j,j,k]:=h1;
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proICnurs[i,j,m,k]:=h1;
      end;
    end;
    // for m:=0 to j do
    //writeln(outfile,'proicnurs',proicnurs[i,j,m,k]:8:3);
  end;
end;
for k:=1 to cycle do
begin
  pnh[0,k]:=1;
  for j:=1 to NH do
  pnh[j,k]:=0;
end;
for k:=1 to cycle do
```

```
begin
  for i:=1 to NC do
  begin
    for l:=1 to maxIC do
    begin
      for m:=0 to NH do
      pnh1[m]:=0;
      for h:=0 to maxop[i] do
      begin
        k2:=k-l;
        if k2<1 then k2:=k2+cycle;
        for j:=0 to h do
        begin
          if h=0 then
          h1:=Stot[i,h,k2] else
          h1:=Stot[i,h,k2]*proICnurs[i,h,j,l];
          if j*Nurse[i,l]<=NH then
          begin
            for m:=0 to NH-(Nurse[i,l]*j) do
            pnh1[m+(j*Nurse[i,l])]:= PNH1[m+(Nurse[i,l]*j)]+PNH[m,k]*h1;
          end;
        end; {for the patients that stay j}
      end; {for number of operations h}
      for m:=0 to NH do
      pnh[m,k]:=PNH1[m];
    end;{for the number of days in ic, l}
  end;{for the type of patients, i}
  writeln(outfile,'nh-day',k:4);
  for m:=0 to NH do
  writeln(outfile,m:4,PNH[m,k]:8:3);
end; {for the day of the cycle k}
for k:=1 to cycle do
begin
  h1:=0;
```

```
  h2:=Tcap[3,k];
  underuse:=0;
  overuse:=0;
  for m:=0 to NH do
  begin
    h1:=h1+m*PNH[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PNH[m,k]
    else
    overuse:=overuse-(h2-m)*PNH[m,k];
  end;
  writeln(outfile,'ENH,underuse,overuse',h1:8:3,Tcap[3,k]:8:3,underuse:8:3,overuse:8:3);
end; {day of the cycle k}
closefile(outfile);
{CALCULATION OF THE MC BEDS}
assignfile(outfile,'emergenciescancPMC.dat');
rewrite(outfile);
for k:=1 to cycle do
for i:=1 to 40 do
pmc[i,k]:=0;
for k:=1 to cycle do
pmc[0,k]:=1;
for i:=1 to NC do
for j:=1 to op do
for k:=-1 to maxMC do
for m:=0 to j do
proMC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do
  begin
    for k:=-1 to maxMC do
    begin
      h1:=1;
```

```
    h2:=cumpercMC[i,k];
    if h2=0 then
    proMC[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proMC[i,j,j,k]:=h1;
      // writeln(outfile,'proMC',i:4,j:4,j:4,k:4,proMC[i,j,j,k]:8:3);
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proMC[i,j,m,k]:=h1;
        //  writeln(outfile,'proMC',i:4,j:4,m:4,k:4,proMC[i,j,m,k]:8:3);
      end;
    end;
  end;{days in the ic k}
end;  {number of operations j}
for k:=1 to cycle do
begin
  plmc[0,k]:=1;
  for m:=1 to 40 do
  plmc[m,k]:=0;
end;
for t:=1 to cycle do
begin
  for l:=-1 to maxMC do
  begin
    if l=-1 then
    begin
      if t=1 then k2:=1+((t+l+cycle-1)mod cycle)
      else
      k2:=1+((t+l-1)mod cycle);
    end;
```

```
    if (l<=cycle) and (l>=0) then
    k2:=1+((t+l-1)mod cycle);
    if l>cycle then  {maxMC>cycle, prob that we have patients
    from the previous cycle on they k of the new cycle}
    k2:=1+((t+l-cycle-1)mod cycle);
    h1:=0;
    for m:=0 to 40 do
    begin
      plmc1[m,k2]:=Plmc[m,k2];
      h1:=h1+plmc[m,k2];
      plmc[m,k2]:=0;
    end;
    for k:=0 to op do
    for j:=0 to k do
    begin
      if k=0 then
      h1:=Stot[i,k,t] else
      h1:=Stot[i,k,t]*proMC[i,k,j,l];
      if (h1>0) and (h1<1) then
      for i1:=40-j downto 0 do
      plmc[i1+j,k2]:=Plmc[i1+j,k2]+Plmc1[i1,k2]*h1;
    end;
  end; {days in the MC l}
end; {day of the cycle t}
for k:=1 to cycle do
begin
  for j:=0 to 40 do
  writeln(outfile,i:4,k:4,Nplan[i,k]:4,Plmc[j,k]:8:3);
  for m:=0 to 40 do
  pmc1[m,k]:=0;
  for j:=0 to 40 do
  for m:=0 to 40-j do
  pmc1[m+j,k]:=PMC1[m+j,k]+PMC[m,k]*plmc[j,k];
  for m:=0 to 40 do
```

```
    pmc[m,k]:=PMC1[m,k];
    h1:=0;
    for m:=0 to 40 do
    h1:=h1+PMC[m,k];
    writeln(outfile,'totkans',h1:8:3);
  end; {days of the cycle,k}
  for k:=1 to cycle do
  begin
    h1:=0;
    for m:=1 to 40 do
    begin
      h1:=h1+PMC[m,k];
      writeln(outfile,'PMC',i:4,m:4,k:4,h1:8:3,PMC[m,k]:8:3);
    end;
  end;
end; {tipo de pacientes (i)}
for k:=1 to cycle do
begin
  h1:=0;
  h2:=Tcap[4,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to 40 do
  begin
    h1:=h1+m*PMC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PMC[m,k]
    else
    overuse:=overuse-(h2-m)*PMC[m,k];
  end;
  writeln(outfile,'EMC,underuse,overuse', h1:8:3,Tcap[4,k]:8:2,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
{Write the file with all the results}
```

```
  assignfile(outfile,'emergenciescancfinal.dat');
rewrite(outfile);
  h3:=0;
  h4:=0;
  for k:=1 to cycle do
  begin
    h1:=0;
    h11:=0;
    overuse:=0;
    underuse:=0;
    for m:=0 to oh do
    begin
      h1:=h1+POT[m,k]*m;
      h11:=h11+POT[m,k]*m*m;
      if k=cycle then
      h2:=Tcap[1,1] else
      h2:=Tcap[1,k+1];
      if m<h2 then
      underuse:=underuse+(h2-m)*POT[m,k]
      else
      overuse:=overuse-(h2-m)*POT[m,k];
    end;
    h14:=h11-(h1*h1);
    writeln(outfile,'day',k:4,'  average OT,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
    h3:=h3+underuse;
    h4:=h4+overuse;
  end;
  writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
  {CALCULO DE LA VARIANCE}
  h1:=0;
  h2:=0;
  h11:=0;
  h12:=0;
  for k:=1 to cycle do
```

```
 begin
 h:=0;
 for i:=1 to NC do
  h:=h+Nplan[i,k];
 if h=0 then
 begin
 for m:=0 to oh do
 begin
 h1:=h1+1;
 h2:=h2+(m*POT[m,k]);
 end;
 end
 else
 for m:=0 to oh do
 begin
 h11:=h11+1;
 h12:=h12+(m*POT[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media POT (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
   h1:=0;
   h11:=0;
   h2:=Tcap[2,k];
   underuse:=0;
   overuse:=0;
   for m:=0 to ic do
   begin
      h1:=h1+m*PIC[m,k];
```

```
      h11:=h11+m*m*PIC[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PIC[m,k]
      else
      overuse:=overuse-(h2-m)*PIC[m,k];
   end;
   h14:=h11-(h1*h1);
   writeln(outfile,'day',k:4,'  average IC,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
 begin
 for m:=0 to ic do
 begin
 h1:=h1+1;
 h2:=h2+(m*PIC[m,k]);
 end;
 end
 else
 for m:=0 to ic do
```

```
 begin
 h11:=h11+1;
 h12:=h12+(m*PIC[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PIC (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
   h1:=0;
   h11:=0;
   h2:=Tcap[3,k];
   underuse:=0;
   overuse:=0;
   for m:=0 to NH do
   begin
      h1:=h1+m*PNH[m,k];
      h11:=h11+m*m*PNH[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PNH[m,k]
      else
      overuse:=overuse-(h2-m)*PNH[m,k];
   end;
   h14:=h11-(h1*h1);
   writeln(outfile,'day',k:4,'  average NH,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
```

```
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
 begin
 for m:=0 to NH do
 begin
 h1:=h1+1;
 h2:=h2+(m*PNH[m,k]);
 end;
 end
 else
 for m:=0 to NH do
 begin
 h11:=h11+1;
 h12:=h12+(m*PNH[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PNH (weekend,normalday)',h3:10:3,h13:10:3);


h3:=0;
h4:=0;
for k:=1 to cycle do
begin
```

```
  h1:=0;
  h11:=0;
  h2:=Tcap[4,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to 40 do
  begin
    h1:=h1+m*PMC[m,k];
    h11:=h11+m*m*PMC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PMC[m,k]
    else
    overuse:=overuse-(h2-m)*PMC[m,k];
  end;
  h14:=h11-(h1*h1);
  writeln(outfile,'day',k:4,'  average MC,variance,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
  h3:=h3+underuse;
  h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;

for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
```

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```
  begin
  for m:=0 to 40 do
  begin
  h1:=h1+(m*m*PMC[m,k]);
  h2:=h2+(m*PMC[m,k]);
  end;
  end
  else
  for m:=0 to 40 do
  begin
  h11:=h11+(m*m*PMC[m,k]);
  h12:=h12+(m*PMC[m,k]);
  end;
  end;


 closefile(outfile);
 button10.Caption:='Done';
end;


procedure TForm1.Button11Click(Sender: TObject);  {cancellation of patients of type 3}
var
    i,j,k,r,count,h,m,x,l,t,i1,k2:integer;
    h1,h2,a,h3,nac:real;
    outfile:textfile;
    maxopem:array[1..NC] of integer;
    plic,plic1,pic,pic1:array[0..ic,1..cycle] of real;
    pbedocup:array[1..NC,0..ic,1..cycle] of real;
    ppacpermtot,Ppacpermtot1:array[0..ic,1..cycle] of real;
    emarr:array[1..7,0..op] of real;
    stot:array[1..NC,0..ic,1..cycle]of real;
    s2:array[0..maxq,1..cycle] of real; {pacients cancelled on day k-1}
    s3:array[0..maxq] of real;
```

```
      pcanc3:array[0..maxq,1..cycle] of real;


begin
   assignfile(outfile,'resultscanpat3.dat');
   rewrite(outfile);
   {calculation of Stot}
   for i:=1 to NC do
   begin
     for k:=1 to 7 do
     begin
       emarr[k,0]:=exp(-empatient[k,i]);
       for j:=1 to op do
       emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/j);
     end;
     for j:=0 to op do
     begin
       for k:=1 to 7 do
       sem[i,j,k]:=emarr[k,j];
       for k:=8 to 14 do
       sem[i,j,k]:=emarr[k-7,j];
       for k:=15 to 21 do
       sem[i,j,k]:=emarr[k-14,j];
       for k:=22 to cycle do
       sem[i,j,k]:=emarr[k-21,j];
     end;
   end;
   for i:=1 to NC do
   begin
     for k:=1 to cycle do
     begin
       for j:=0 to maxop[i] do
       begin
         if j=0 then Stot[i,0,k]:=S[i,0,k]*Sem[i,0,k]
```

```
        else
        begin
          stot[i,j,k]:=0;
          if j>=Nplan[i,k] then
          begin
            for x:=0 to Nplan[i,k] do
            stot[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
          end;
          if j<Nplan[i,k] then
          begin
            for x:=0 to j do
            if x<=op then
            stot[i,j,k]:=Sem[i,j-x,k]*S[i,x,k]+Stot[i,j,k];
          end;
        end;
      end;
      for j:=maxop[i]+1 to ic do
      stot[i,j,k]:=0;
     { for j:=0 to ic do
      writeln (outfile,'Stot',i:4,j:4,k:4,Stot[i,j,k]:8:3); }
  end;
end;
for k:=1 to cycle do
for i:=1 to nc do
for j:=0 to ic do
if (i=3) then Stot1[3,j,k]:=Sem[3,j,k]
else
stot1[i,j,k]:=Stot[i,j,k];
for k:=1 to cycle do
for j:=0 to op do
s2[j,k]:=0;
for k:=1 to cycle do
for i:=1 to ic do
pic[i,k]:=0;
```

```
for k:=1 to cycle do
pic[0,k]:=1;
for i:=1 to NC do
for j:=1 to op do
for k:=1 to maxIC do
for m:=0 to j do
proIC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do      {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
    h1:=1;
    h2:=cumpercIC[i,k];
    if h2=0 then
    proIC[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proIC[i,j,j,k]:=h1;
      //writeln(outfile,'proic', i:4,j:4,j:4,k:4, ProIC[i,j,j,k]:8:3);
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proIC[i,j,m,k]:=h1;
        // writeln(outfile,'proic', i:4,j:4,m:4,k:4, ProIC[i,j,m,k]:8:3);
      end;
    end;
  end;  {end of the bucle for k}
  for k:=1 to cycle do
  begin
    plic[0,k]:=1;
    for m:=1 to ic do
```

```
  plic[m,k]:=0;
end;
for k:=1 to cycle do
begin
  for l:=1 to maxIC do
  begin
    k2:=1+((k+l-1)mod cycle);
    h1:=0;
    for m:=0 to ic do
    begin
      plic1[m,k2]:=Plic[m,k2];
      h1:=h1+plic[m,k2];
      plic[m,k2]:=0;
    end;
    for t:=0 to op do
    for j:=0 to t do
    begin
      if t=0 then
      h1:=Stot1[i,t,k] else
      h1:=Stot1[i,t,k]*ProIC[i,t,j,l];
      if (h1>0) and (h1<1) then
      for i1:=ic-j downto 0 do
      plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
    end;
  end; {dias que permanecen en IC l}
end;
for k:=1 to cycle do
begin
  for m:=0 to ic do
  pic1[m,k]:=0;
  for j:=0 to ic do
  for m:=0 to ic-j do
  pic1[m+j,k]:= PIC1[m+j,k]+PIC[m,k]*Plic[j,k];
  for m:=0 to ic do
```

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```
    pic[m,k]:=PIC1[m,k];
    h1:=0;
    for m:=1 to ic do
    h1:=h1+pic[m,k];
    pic[0,k]:=1-h1;
  end;{ dias del ciclo k}
  for k:=1 to cycle do
  for j:=0 to ic do
  writeln(outfile,'pic',j:4,Pic[j,k]:8:3,plic[j,k]:8:3,Stot1[i,j,k]:8:3);
end;{tipo de pacientes i}


{-------------- principio del calculo recursivo -----------------}
for j:=0 to op do
  for k:=1 to cycle do
  s1[3,j,k]:=S[3,j,k];
for k:=1 to cycle do
begin
S2[0,k]:=1;
for j:=1 to maxq do
S2[j,k]:=0;
end;
for count:=1 to simduurcanc do
begin
nac:=0;
  for k:=1 to cycle do
  begin
  h1:=0;
    {añadir los pacientes en cola al dia siguiente}
    for j:=0 to maxq do
    begin
      s3[j]:=0;
      for x:=0 to j do
      if x<=Nplan[3,k] then
```

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```
    s3[j]:=S[3,x,k]*S2[j-x,k]+S3[j]; {old S+cancellations}
  h1:=h1+s3[j];
end;
s3[0]:=s3[0]+1-h1;
writeln(outfile,'s3-tot',h1:8:4);
ppacpermtot[0,k]:=1;
for m:=1 to ic do
ppacpermtot[m,k]:=0;
for l:=1 to maxIC-1 do
begin
  k2:=k-l;
 if k2<=0 then
 k2:=k2+cycle;
   if Nplan[3,k2]>0 then
   begin
  for j:=0 to ic do
  begin
    ppacpermtot1[j,k]:=Ppacpermtot[j,k];
    ppacpermtot[j,k]:=0;
  end; {para las camas ocupadas j}

 for j:=0 to Nplan[3,k2] do
  for x:=0 to j do
  begin
    if j=0 then h1:=S1[3,j,k2]
    else
    h1:=S1[3,j,k2]*proIC[3,j,x,l+1];
    if (h1>0) and (h1<1) then
    for i1:=ic-x downto 0 do
    ppacpermtot[i1+x,k]:=Ppacpermtot[i1+x,k]+Ppacpermtot1[i1,k]*h1;
  end; {numero de camas ocupadas j y x}
end;
h1:=0;
for j:=1 to op do
```

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```
 h1:=ppacpermtot[j,k]+h1;
 if h1<1 then
 Ppacpermtot[0,k]:=1-h1;
   end; {para los dias en IC l}
// for j:=0 to op do
// writeln(outfile,'k,j,S1,s3,Pic,ppac',k:4,j:4,S1[3,j,k]:8:3,s3[j]:8:3,PIc[j,k]:8:3,ppacpermtot[j,k]:8:3);
  for j:=0 to ic do
pbedocup[3,j,k]:=0;
h1:=0;
for j:=0 to ic do
h1:=h1+pic[j,k];
writeln(outfile,'pbedocup',h1:8:4);
 for j:=0 to ic do
 for x:=0 to j do
 pbedocup[3,j,k]:=PIC[j-x,k]*Ppacpermtot[x,k]+Pbedocup[3,j,k];

 for j:=0 to ic do {S1 are the admited pacients for category 3, the new S}
 s1[3,j,k]:=0;
 if nplan[3,k]=0 then
 begin
    s1[3,0,k]:=1;
    for j:=0 to maxq do
    S2[j,(k mod cycle)+1]:=S2[j,k];
 end
 else
 begin
 for x:=0 to maxq do
 if S3[x]>0.00000001 then
 for j:=0 to ic do
 begin
    if x+j<=icbed then
    begin
       if x<=Nplan[3,k] then
       s1[3,x,k]:=S1[3,x,k]+S3[x]*Pbedocup[3,j,k]
```

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```
      else
      s1[3,Nplan[3,k],k]:= S1[3,Nplan[3,k],k]+S3[x]*Pbedocup[3,j,k];
    end
    else
    if j<icbed then
    begin
      if (icbed-j)<=Nplan[3,k] then
      s1[3,icbed-j,k]:=S1[3,icbed-j,k]+S3[x]*Pbedocup[3,j,k]
      else
      s1[3,Nplan[3,k],k]:= S1[3,Nplan[3,k],k]+S3[x]*Pbedocup[3,j,k];
    end
    else
    s1[3,0,k]:=S1[3,0,k]+S3[x]*Pbedocup[3,j,k];
end; {numero de pacientes admitidos j}
for j:=0 to Nplan[3,k] do
nac:=nac+j*S1[3,j,k];
{calculo de S2}{S2 are the cancellations due to the new S}
if k=cycle then
begin
    for j:=0 to maxq do
    s2[j,1]:=0;
    for x:=0 to maxq do
    if S3[x]>0.00000001 then
    for j:=0 to ic do
    begin
      if x+j<=icbed then
      begin
        if x<=Nplan[3,k] then
        s2[0,1]:=S2[0,1]+ S3[x]*Pbedocup[3,j,k]
        else
        s2[x-Nplan[3,k],1]:=S2[x-Nplan[3,k],1]+ S3[x]*Pbedocup[3,j,k];
      end
      else
      if j<icbed then
```

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```
    begin
      if x>(icbed-j) then
      s2[x-(icbed-j),1]:=S2[x-(icbed-j),1]+S3[x]*Pbedocup[3,j,k]
      else
      begin
        if (icbed-j)<=Nplan[3,k] then
        s2[0,1]:=S2[0,1]+S3[x]*Pbedocup[3,j,k]
        else
        s2[x-Nplan[3,k],1]:=S2[x-Nplan[3,k],1]+ S3[x]*Pbedocup[3,j,k];
      end;
    end
    else
    s2[x,1]:=S2[x,1]+S3[x]*Pbedocup[3,j,k];
  end; {numero de pacientes admitidos j}
end{para k=cycle}
else
begin
  for j:=0 to maxq do {S2 are the cancellations due to the new S}
  s2[j,k+1]:=0;
  for x:=0 to maxq do
  if S3[x]>0.00000001 then
  for j:=0 to ic do
  begin
    if x+j<=icbed then
    begin
      if x<=Nplan[3,k] then
      s2[0,k+1]:=S2[0,k+1]+ S3[x]*Pbedocup[3,j,k]
      else
      s2[x-Nplan[3,k],k+1]:=S2[x-Nplan[3,k],k+1]+ S3[x]*Pbedocup[3,j,k];
    end
    else
    if j<icbed then
    begin
      if x>(icbed-j) then
```

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```
          s2[x-(icbed-j),k+1]:=S2[x-(icbed-j),k+1]+S3[x]*Pbedocup[3,j,k]
          else
          begin
            if (icbed-j)<=Nplan[3,k] then
            s2[0,k+1]:=S2[0,k+1]+S3[x]*Pbedocup[3,j,k]
            else
            s2[x-Nplan[3,k],k+1]:=S2[x-Nplan[3,k],k+1]+ S3[x]*Pbedocup[3,j,k];
          end;
        end
        else
        s2[x,k+1]:=S2[x,k+1]+S3[x]*Pbedocup[3,j,k];
      end; {numero de pacientes admitidos j}
    end; {calculo de S2 si k es diferente de cycle}
    end;{for nplan>0}
    //  for j:=0 to op do
   // writeln(outfile,'k,j,S1,S3,S2,pbed',k:4,j:4,S1[3,j,k]:8:3,S3[j]:8:3,S2[j,k]:8:3,Pbedocup[3,j,k]:8:3);

  end; {dias del ciclo k}
  writeln(outfile,'nac',nac:8:3);
end;{para el bucle de count}
for k:=1 to cycle do
for j:=0 to op do
writeln(outfile,'k,j,S1,S,Pbed,S2,S3',k:4,j:4,S1[3,j,k]:8:3,S[3,j,k]:8:3,Pbedocup[3,j,k]:8:3,
s2[j,k]:8:3,S3[j]:8:3);
for k:=1 to cycle do
begin
for j:=0 to maxq do
pcanc3[j,k]:=0;
  for j:=0 to maxq do
  for x:=0 to Nplan[3,k] do
  for l:=0 to ic do
  begin
    k2:=icbed-l;
    if k2<0 then k2:=0;
```

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```
    if k2>Nplan[3,k] then
    k2:=Nplan[3,k];
    k2:=k2-j;
    if k2<0 then k2:=0;
    k2:=x-k2;
    if k2<0 then k2:=0;
    pcanc3[k2,k]:=  pcanc3[k2,k]+S2[j,k]*Pbedocup[3,l,k]*S[3,x,k];
   end;

h1:=0;
for j:=1 to maxq do
h1:=pcanc3[j,k]+h1;
pcanc3[0,k]:=1-h1;
end;
for k:=1 to cycle do
for j:=0 to op do
writeln(outfile,'k,j,Pcanc3', k:4,j:4,Pcanc3[j,k]:8:3);
for k:=1 to cycle do
begin
h1:=0;
for j:=0 to maxq do
h1:=pcanc3[j,k]*j+h1;
writeln(outfile,'totpcanc3',k:4,h1:8:3);
end;
{calculation of the new waiting time for patients of category 3}
 h2:=0;
 for k:=1 to cycle do
 for j:=0 to maxq do
 h2:=h2+j*S2[j,k];
 h1:=h2/28;
 h3:=h1+we;
 writeln(outfile,'watchenden',h3:8:3,we:8:3);
 h2:=h2/lambdapatient[3];
 h3:=h2+wt;
```

```
 writeln(outfile,'new waiting time 3',h3:8:3,wt:8:3);
  closefile(outfile);
  button11.Caption:='Done';
end; {procedure button 11}



procedure TForm1.Button12Click(Sender: TObject);  {cancellation of some patients of type 3}



var
    i,j,k,r,k2,count,h,m,x,l,t,i1:integer;
    h1,h2,h3,h4,h11,h12,h13,h14,v,v1,underuse,overuse,capn1,capn2,a:real;
    outfile:textfile;
    stot,StotDAY:array[1..NC,0..ic,1..cycle]of real; {prob to have j operations of type i on day k }
    plic,plic1,pic,pic1:array[0..ic,1..cycle] of real;
    pnh:array[0..NH,1..cycle] of real; {prob to have m nursing hours on day k}
    pnh1:array[0..NH] of real;
    plmc,plmc1,pmc,PMC1:array[0..40,1..cycle] of real;{prob de que hayan m pacientes en MC el dia k}
    pot,POT1:array[0..oh,1..cycle] of real;
    fact:array[0..op,0..op] of real; {funcion factorial}
    emarr:array[1..7,0..op] of real; {prob to have j arrivals of emergency patients on day k}
    arr:array[0..100] of real;{probability of having j arrivals}
    q,q1:array[0..100,1..cycle] of real; {probability to have k patients on day k}
    {CALCULATION OF THE NEW Stot}
begin
  assignfile(outfile,'type3 cancStot.dat');
  rewrite(outfile);
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/j);
```

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```
  end;
  for j:=0 to op do
  begin
    for k:=1 to 7 do
    sem[i,j,k]:=emarr[k,j];
    for k:=8 to 14 do
    sem[i,j,k]:=emarr[k-7,j];
    for k:=15 to 21 do
    sem[i,j,k]:=emarr[k-14,j];
    for k:=22 to cycle do
    sem[i,j,k]:=emarr[k-21,j];
  end;
end;
for k:=1 to cycle do
for i:=1 to nc do
for j:=0 to ic do
if (i=3) then S1[3,j,k]:=S1[3,j,k]
else
s1[i,j,k]:=S[i,j,k];
for i:=1 to NC do
begin
  for k:=1 to cycle do
  begin
    for j:=0 to maxop[i] do
    begin
      if j=0 then Stot[i,0,k]:=S1[i,0,k]*Sem[i,0,k]
      else
      begin
        stot[i,j,k]:=0;
        if j>=Nplan[i,k] then
        begin
          for x:=0 to Nplan[i,k] do
          stot[i,j,k]:=Sem[i,j-x,k]*S1[i,x,k]+Stot[i,j,k];
        end;
```

```
          if j<Nplan[i,k] then
          begin
            for x:=0 to j do
            if x<=op then
            stot[i,j,k]:=Sem[i,j-x,k]*S1[i,x,k]+Stot[i,j,k];
          end;
        end;
      end;
      for j:=maxop[i]+1 to ic do
      stot[i,j,k]:=0;
      for j:=0 to maxop[i] do
      writeln (outfile,'Stot',i:4,j:4,k:4,Stot[i,j,k]:8:3);
    end;
  end;
  for i:=1 to NC do
  begin
    for k:=1 to 7 do
    begin
      emarr[k,0]:=exp(-empatient[k,i]/3);
      for j:=1 to op do
      emarr[k,j]:= emarr[k,j-1]*(empatient[k,i]/(j*3));
    end;
    for j:=0 to op do
    begin
      for k:=1 to 7 do
      sem1[i,j,k]:=emarr[k,j];
      for k:=8 to 14 do
      sem1[i,j,k]:=emarr[k-7,j];
      for k:=15 to 21 do
      sem1[i,j,k]:=emarr[k-14,j];
      for k:=22 to cycle do
      sem1[i,j,k]:=emarr[k-21,j];
    end;
  end;
```

```
for i:=1 to NC do
begin
  for k:=1 to cycle do
  begin
    for j:=0 to maxop[i] do
    begin
      stotDAY[i,j,k]:=0;
      if j>=Nplan[i,k] then
      begin
        for x:=0 to Nplan[i,k] do
        stotDAY[i,j,k]:=Sem1[i,j-x,k]*S1[i,x,k]+StotDAY[i,j,k];
      end;
      if j<Nplan[i,k] then
      begin
        for x:=0 to j do
        stotDAY[i,j,k]:=Sem1[i,j-x,k]*S1[i,x,k]+StotDAY[i,j,k];
      end;
      writeln (outfile,'StotDAY',i:4,j:4,k:4,StotDAY[i,j,k]:8:3);
    end; {para el numero de operaciones realizadas j}
  end;{para los dias del ciclo en que se realiza k}
end; {para el tipo de pacientes i}
closefile(outfile);
{CALCULATION OF THE OT HOURS}
assignfile(outfile,'type3 cancPOT.dat');
rewrite(outfile);
for k:=1 to cycle do
for m:=0 to oh do
pot[m,k]:=0;
for k:=1 to cycle do
begin
  pot[0,k]:=1;
  for i:=1 to NC do
  begin
    for m:=0 to oh do
```

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```
    pot1[m,k]:=0;
    for j:=0 to maxop[i] do
    if j*ot[i]<=oh then
    for m:=0 to oh-(j*ot[i]) do
    pot1[m+(j*ot[i]),k]:=POT1[m+(j*ot[i]),k]+POT[m,k]*StotDAY[i,j,k];
    for m:=0 to oh do
    pot[m,k]:=POT1[m,k];
  end; {type of patients (i)}
  writeln(outfile,'ot-day',k:4);
  for m:=0 to oh do
  writeln(outfile,m:4,POT[m,k]:8:3);
end; {dia del ciclo k}
for k:=1 to cycle do
begin
  underuse:=0;
  overuse:=0;
  h1:=0;
  for m:=0 to oh do
  begin
    h1:=h1+POT[m,k]*m;
    if k=cycle then
    h2:=Tcap[1,1] else
    h2:=Tcap[1,k+1];
    if m<h2 then
    underuse:=underuse+(h2-m)*POT[m,k]
    else
    overuse:=overuse-(h2-m)*POT[m,k];
  end;{numero de horas operando m}
  writeln(outfile,'average OT,underuse,overuse', h1:8:3,underuse:8:3,overuse:8:3);
end;{dia del ciclo k}
closefile(outfile);
{CALCULATION OF THE IC BEDS}
assignfile(outfile,'type3 cancPIC.dat');
rewrite(outfile);
```

```
for i:=1 to NC do
for j:=1 to op do
for k:=1 to maxIC do
for m:=0 to j do
proIC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do      {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
    h1:=1;
    h2:=cumpercIC[i,k];
    if h2=0 then
    proIC[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proIC[i,j,j,k]:=h1;
      //writeln(outfile,'proic', i:4,j:4,j:4,k:4, ProIC[i,j,j,k]:8:3);
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proIC[i,j,m,k]:=h1;
        // writeln(outfile,'proic', i:4,j:4,m:4,k:4, ProIC[i,j,m,k]:8:3);
      end;
    end;
  end;
end;
for k:=1 to cycle do
begin
  pic[0,k]:=1;
  for m:=1 to ic do
  pic[m,k]:=0;
```

```
end;
for i:=1 to nc do
begin
  for k:=1 to cycle do
  begin
    plic[0,k]:=1;
    for m:=1 to ic do
    plic[m,k]:=0;
  end;
  for t:=1 to cycle do
  for l:=1 to maxIC do
  begin
    k2:=1+((t+l-1)mod cycle);
    h1:=0;
    for m:=0 to ic do
    begin
      plic1[m,k2]:=Plic[m,k2];
      h1:=h1+plic[m,k2];
      plic[m,k2]:=0;
    end;
    for k:=0 to op do
    begin
      for j:=0 to k do
      begin
        if k=0 then
        h1:=Stot[i,k,t] else
        h1:=Stot[i,k,t]*ProIC[i,k,j,l];
        if (h1>0) and (h1<1) then
        for i1:=ic-j downto 0 do
        plic[i1+j,k2]:=Plic[i1+j,k2]+Plic1[i1,k2]*h1;
      end;
    end;
  end;
  for k:=1 to cycle do
```

```
  begin
    for m:=0 to ic do
    pic1[m,k]:=0;
    for j:=0 to ic do
    for m:=0 to ic-j do
    pic1[m+j,k]:= PIC1[m+j,k]+PIC[m,k]*Plic[j,k];
    for m:=0 to ic do
    pic[m,k]:=PIC1[m,k];
    h1:=0;
    for m:=0 to ic do
    h1:=h1+pic[m,k];
    // writeln(outfile,'totkans',h1:8:3);
  end;
  for k:=1 to cycle do
  for m:=0 to ic do
  writeln(outfile,'PIC',i:4,m:4,k:4,PIC[m,k]:8:3)
end; {type of patients i}
for k:=1 to cycle do
begin
  h1:=0;
  h2:=Tcap[2,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to ic do
  begin
    h1:=h1+m*PIC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PIC[m,k]
    else
    overuse:=overuse-(h2-m)*PIC[m,k];
  end;
  writeln(outfile,'EIC,underuse,overuse', h1:8:3,Tcap[2,k]:8:2,underuse:8:3,overuse:8:3);
end;
closefile(outfile);
```

```
{CALCULATION OF THE NH}
assignfile(outfile,'type3 cancPNH.dat');
rewrite(outfile);
for i:=1 to NC do
for j:=1 to ic do
for k:=1 to maxIC do
for m:=0 to j do
proICnurs[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to ic do      {calculate prob that patients are still in IC}
  for k:=1 to maxIC do
  begin
    if Nurse[i,k]=0 then
    h2:=0
    else
    begin
      h1:=1;
      h2:=cumpercICnurs[i,k]/Nurse[i,k];
    end;
    if h2=0 then
    proICnurs[i,j,0,k]:=1
    else
    begin
      for m:=1 to j do
      h1:=h1*h2;
      proICnurs[i,j,j,k]:=h1;
      for m:=j-1 downto 0 do
      begin
        h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
        proICnurs[i,j,m,k]:=h1;
      end;
    end;
    // for m:=0 to j do
```

```
    //writeln(outfile,'proicnurs',proicnurs[i,j,m,k]:8:3);
  end;
end;
for k:=1 to cycle do
begin
  pnh[0,k]:=1;
  for j:=1 to NH do
  pnh[j,k]:=0;
end;
for k:=1 to cycle do
begin
  for i:=1 to NC do
  begin
    for l:=1 to maxIC do
    begin
      for m:=0 to NH do
      pnh1[m]:=0;
      for h:=0 to maxop[i] do
      begin
        k2:=k-l;
        if k2<1 then k2:=k2+cycle;
        for j:=0 to h do
        begin
          if h=0 then
          h1:=Stot[i,h,k2] else
          h1:=Stot[i,h,k2]*proICnurs[i,h,j,l];
          if j*Nurse[i,l]<=NH then
          begin
            for m:=0 to NH-(Nurse[i,l]*j) do
            pnh1[m+(j*Nurse[i,l])]:= PNH1[m+(Nurse[i,l]*j)]+PNH[m,k]*h1;
          end;
        end; {for the patients that stay j}
      end; {for number of operations h}
      for m:=0 to NH do
```

```
        pnh[m,k]:=PNH1[m];
      end;{for the number of days in ic, l}
    end;{for the type of patients, i}
    writeln(outfile,'nh-day',k:4);
    for m:=0 to NH do
    writeln(outfile,m:4,PNH[m,k]:8:3);
  end; {for the day of the cycle k}
  for k:=1 to cycle do
  begin
    h1:=0;
    h2:=Tcap[3,k];
    underuse:=0;
    overuse:=0;
    for m:=0 to NH do
    begin
      h1:=h1+m*PNH[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PNH[m,k]
      else
      overuse:=overuse-(h2-m)*PNH[m,k];
    end;
    writeln(outfile,'ENH,underuse,overuse',h1:8:3,Tcap[3,k]:8:3,underuse:8:3,overuse:8:3);
  end; {day of the cycle k}
  closefile(outfile);
  {CALCULATION OF THE MC BEDS}
  assignfile(outfile,'type3 cancPMC.dat');
  rewrite(outfile);
  for k:=1 to cycle do
  for i:=1 to 40 do
  pmc[i,k]:=0;
  for k:=1 to cycle do
  pmc[0,k]:=1;
  for i:=1 to NC do
  for j:=1 to op do
```

```
for k:=-1 to maxMC do
for m:=0 to j do
proMC[i,j,m,k]:=0;
for i:=1 to NC do
begin
  for j:=1 to op do
  begin
    for k:=-1 to maxMC do
    begin
      h1:=1;
      h2:=cumpercMC[i,k];
      if h2=0 then
      proMC[i,j,0,k]:=1
      else
      begin
        for m:=1 to j do
        h1:=h1*h2;
        proMC[i,j,j,k]:=h1;
        // writeln(outfile,'proMC',i:4,j:4,j:4,k:4,proMC[i,j,j,k]:8:3);
        for m:=j-1 downto 0 do
        begin
          h1:=h1*(1-h2)*(m+1)/(h2*(j-m));
          proMC[i,j,m,k]:=h1;
          //  writeln(outfile,'proMC',i:4,j:4,m:4,k:4,proMC[i,j,m,k]:8:3);
        end;
      end;
    end;{days in the ic k}
  end;  {number of operations j}
  for k:=1 to cycle do
  begin
    plmc[0,k]:=1;
    for m:=1 to 40 do
    plmc[m,k]:=0;
  end;
```

```
for t:=1 to cycle do
begin
  for l:=-1 to maxMC do
  begin
    if l=-1 then
    begin
      if t=1 then k2:=1+((t+l+cycle-1)mod cycle)
      else
      k2:=1+((t+l-1)mod cycle);
    end;
    if (l<=cycle) and (l>=0) then
    k2:=1+((t+l-1)mod cycle);
    if l>cycle then  {maxMC>cycle, prob that we have patients
    from the previous cycle on they k of the new cycle}
    k2:=1+((t+l-cycle-1)mod cycle);
    h1:=0;
    for m:=0 to 40 do
    begin
      plmc1[m,k2]:=Plmc[m,k2];
      h1:=h1+plmc[m,k2];
      plmc[m,k2]:=0;
    end;
    for k:=0 to op do
    for j:=0 to k do
    begin
      if k=0 then
      h1:=Stot[i,k,t] else
      h1:=Stot[i,k,t]*proMC[i,k,j,l];
      if (h1>0) and (h1<1) then
      for i1:=40-j downto 0 do
      plmc[i1+j,k2]:=Plmc[i1+j,k2]+Plmc1[i1,k2]*h1;
    end;
  end; {days in the MC l}
end; {day of the cycle t}
```

```
  for k:=1 to cycle do
  begin
    for j:=0 to 40 do
    writeln(outfile,i:4,k:4,Nplan[i,k]:4,Plmc[j,k]:8:3);
    for m:=0 to 40 do
    pmc1[m,k]:=0;
    for j:=0 to 40 do
    for m:=0 to 40-j do
    pmc1[m+j,k]:=PMC1[m+j,k]+PMC[m,k]*plmc[j,k];
    for m:=0 to 40 do
    pmc[m,k]:=PMC1[m,k];
    h1:=0;
    for m:=0 to 40 do
    h1:=h1+PMC[m,k];
    writeln(outfile,'totkans',h1:8:3);
  end; {days of the cycle,k}
  for k:=1 to cycle do
  begin
    h1:=0;
    for m:=1 to 40 do
    begin
      h1:=h1+PMC[m,k];
      writeln(outfile,'PMC',i:4,m:4,k:4,h1:8:3,PMC[m,k]:8:3);
    end;
  end;
end; {tipo de pacientes (i)}
for k:=1 to cycle do
begin
  h1:=0;
  h2:=Tcap[4,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to 40 do
  begin
```

```
      h1:=h1+m*PMC[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PMC[m,k]
      else
      overuse:=overuse-(h2-m)*PMC[m,k];
    end;
    writeln(outfile,'EMC,underuse,overuse', h1:8:3,Tcap[4,k]:8:2,underuse:8:3,overuse:8:3);
  end;
  closefile(outfile);
  {---------------------Write the file with all the results---------------------}
  assignfile(outfile,'type3 cancfinal.dat');
rewrite(outfile);
  h3:=0;
  h4:=0;
  for k:=1 to cycle do
  begin
    h1:=0;
    h11:=0;
    overuse:=0;
    underuse:=0;
    for m:=0 to oh do
    begin
      h1:=h1+POT[m,k]*m;
      h11:=h11+POT[m,k]*m*m;
      if k=cycle then
      h2:=Tcap[1,1] else
      h2:=Tcap[1,k+1];
      if m<h2 then
      underuse:=underuse+(h2-m)*POT[m,k]
      else
      overuse:=overuse-(h2-m)*POT[m,k];
    end;
    h14:=h11-(h1*h1);
    writeln(outfile,'day',k:4,'  average OT,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
```

```
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
  h:=h+Nplan[i,k];
 if h=0 then
 begin
 for m:=0 to oh do
 begin
 h1:=h1+1;
 h2:=h2+(m*POT[m,k]);
 end;
 end
 else
 for m:=0 to oh do
 begin
 h11:=h11+1;
 h12:=h12+(m*POT[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media POT (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
```

```
for k:=1 to cycle do
begin
   h1:=0;
   h11:=0;
   h2:=Tcap[2,k];
   underuse:=0;
   overuse:=0;
   for m:=0 to ic do
   begin
      h1:=h1+m*PIC[m,k];
      h11:=h11+m*m*PIC[m,k];
      if m<h2 then
      underuse:=underuse+(h2-m)*PIC[m,k]
      else
      overuse:=overuse-(h2-m)*PIC[m,k];
   end;
   h14:=h11-(h1*h1);
   writeln(outfile,'day',k:4,'  average IC,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
   h3:=h3+underuse;
   h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
```

```
 if h=0 then
 begin
 for m:=0 to ic do
 begin
 h1:=h1+1;
 h2:=h2+(m*PIC[m,k]);
 end;
 end
 else
 for m:=0 to ic do
 begin
 h11:=h11+1;
 h12:=h12+(m*PIC[m,k]);
 end;
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PIC (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
  h1:=0;
  h11:=0;
  h2:=Tcap[3,k];
  underuse:=0;
  overuse:=0;
  for m:=0 to NH do
  begin
    h1:=h1+m*PNH[m,k];
    h11:=h11+m*m*PNH[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PNH[m,k]
    else
```

```
      overuse:=overuse-(h2-m)*PNH[m,k];
    end;
    h14:=h11-(h1*h1);
    writeln(outfile,'day',k:4,'  average NH,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
    h3:=h3+underuse;
    h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
 begin
 h:=0;
 for i:=1 to NC do
 if k=1 then h:=h+NPlan[i,cycle]
 else
  h:=h+Nplan[i,k-1];
 if h=0 then
 begin
 for m:=0 to NH do
 begin
 h1:=h1+1;
 h2:=h2+(m*PNH[m,k]);
 end;
 end
 else
 for m:=0 to NH do
 begin
 h11:=h11+1;
 h12:=h12+(m*PNH[m,k]);
 end;
```

```
 end;
 h3:=h2/8;
 h13:=h12/20;
 writeln(outfile,'media PNH (weekend,normalday)',h3:10:3,h13:10:3);
h3:=0;
h4:=0;
for k:=1 to cycle do
begin
  h1:=0;
  h11:=0;
  h2:=Tcap[4,k];
  underuse:=0;
  overuse:=0;
  for m:=1 to 40 do
  begin
    h1:=h1+m*PMC[m,k];
    h11:=h11+m*m*PMC[m,k];
    if m<h2 then
    underuse:=underuse+(h2-m)*PMC[m,k]
    else
    overuse:=overuse-(h2-m)*PMC[m,k];
  end;
  h14:=h11-(h1*h1);
  writeln(outfile,'day',k:4,'  average MC,variance,underuse,overuse', h1:8:3,h14:10:3,underuse:8:3,overuse:8:3);
  h3:=h3+underuse;
  h4:=h4+overuse;
end;
writeln(outfile,'totunderuse,totoveruse',h3:8:3,h4:8:3);
{CALCULO DE LA VARIANCE}
h1:=0;
h2:=0;
h11:=0;
h12:=0;
for k:=1 to cycle do
```

```
  begin
  h:=0;
  for i:=1 to NC do
  if k=1 then h:=h+NPlan[i,cycle]
  else
   h:=h+Nplan[i,k-1];
  if h=0 then
  begin
  for m:=0 to 40 do
  begin
  h1:=h1+(m*m*PMC[m,k]);
  h2:=h2+(m*PMC[m,k]);
  end;
  end
  else
  for m:=0 to 40 do
  begin
  h11:=h11+(m*m*PMC[m,k]);
  h12:=h12+(m*PMC[m,k]);
  end;
  end;
 closefile(outfile);
 button12.Caption:='Done';
end;
end.
```

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