



An automated scheduling system for radiotherapy physicist on-call using Monte Carlo simulation

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Abstract

An automated physicist on-call program was developed to support emergency radiotherapy in a cancer centre. A computer program was created to generate an on-call schedule according to the credit score approach. Monte Carlo method was used to simulate the number of treatment cases per shift of on-call physicists (total 32) based on 8 years of data (2010–2017), and the “Most Credit First” criteria was used to justify the order of physicists in the schedule. Evaluation of the old schedule, in which the physicists were randomly assigned, with the new one was carried out. The deviations of mean for the number of shifts and treatment cases for every physicist were determined between the new and old schedule. By considering the on-call physicists who contributed more than or equal to 10 shifts of treatment cases in 2010–2017, in the old schedule there were 6 physicists having shifts and treatment cases greater than 30% of the mean values. While in the new schedule, nobody has similar workloads over 30% of the mean during the same year range. Using the new scheduling method, the mean number of shifts was reduced from 16.5 to 11.8 per physicist, and the mean number of treatment cases was reduced from 25.6 to 19.7 per physicist, as compared to the old schedule. It is concluded that our new method based on Monte Carlo simulation and credit score approach can produce a more equitable physicist on-call schedule for a list of physicists in the emergency radiotherapy program. The workload balance using our new method is better than our old method that assigned physicists randomly.

Keywords Emergency radiotherapy · Physics on-call · Monte Carlo simulation · Credit scoring method · Data analysis

Introduction

In emergency radiotherapy, the patient is often under palliative care and has to be treated within 2–3 h [1–4]. Outside office hours during weekdays and 24 h during weekends/public holidays, an on-call radiotherapy team including an radiation oncologist, radiotherapists and medical physicist is set up. This poses several challenges. First, when an emergency radiotherapy case happens, all members in the team are expected to report immediately to the cancer centre. This is stressful for the team, but to intensify health service

delivery, all team members have to standby outside office hours [1, 5]. Second, we have had issues of computer network malfunction from the cancer centre, losing connection to the staff, and even his/her backup during the off-hour (on the train/subway going home) period, and after midnight (e.g. 3–5 am).

For the medical physicist on-call team, understandably, everybody wishes to have minimum treatment case in the shift (usually 1 week) due to the above uncertainties, it is important to have a fair scheduling system that maintains a workload balance, considering the number of cases per week. However, the on-call scheduling is usually done by the on-call physics leader assigning physicists randomly according to their availability. This means that there is an added workload to the physics leader as well as risk of personal bias when scheduling. Moreover, due to the unpredictability of emergency treatments some physicists may be performing many more cases in comparison to others, despite being scheduled for the same amount of shifts, causing a substantial increase in workload and stress. To avoid the imbalance of workload among all physicists in

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the on-call team, Monte Carlo simulation and the credit scoring method are proposed to generate a physicist on-call schedule. This method uses a credit-based system whereby a physicist is scheduled based on a given credit score [6]. As he/she is scheduled, some of his/her credit is used up allowing the next highest credit scored to be scheduled. This method is prevalent in the field of networking in regard to prioritizing workloads. By treating each on-call physicist as a “server” to be selected and the amount of treatment cases predicted to be worked for a given shift treated as the incoming data, then the credit score approach is applicable in this context.

Still, a challenge using the above credit scoring method is how to predict the number of treatment case per shift accurately to avoid problems of bias and uncertainty. In health-care services such as emergency radiotherapy, the trend of treatment case per period of time can be predicted by Monte Carlo simulation [7]. Monte Carlo method on health services has been widely used in different areas. For example, Kennedy reviewed the use of Monte Carlo method to solve administrative problems regarding spreadsheet add-ins, process simulation software, and discrete event simulation software [8]. These problems were solved by Monte Carlo simulations with probability distributions integrated into models of the health care environment. Kennedy pointed out that Monte Carlo method can be used to find out solutions for facility planning, resource allocation, staffing, patient flow and wait time, routing and transportation, supply chain management and process improvement [8]. Antognini et al. used Monte Carlo simulation to predict how many operating rooms are needed to manage non-elective surgical cases [9]. Based on the patient arrival data and surgical procedure length from their institution, they concluded that the simulation could guide decisions on how to balance resources for elective and non-elective surgical procedures. In addition, Liu developed a generic bed planning model using Monte Carlo simulation [10]. Liu determined the waiting time in emergency rooms based on the prediction of patient demand for beds in a hospital during a typical week.

In this study, we will use our proposed automatic scheduling method based on Monte Carlo simulation and the credit score approach to evaluate the workload balance of the physicist on-call program at the Princess Margate Cancer Centre in 2010–2017.

Methods

From February 2010 to December 2017, there were 658 emergency radiotherapy cases recorded in the cancer centre. There were 32 on-call physicists involved in the program supporting the emergency radiotherapy delivery.

Workflow of the automatic on-call scheduling

Figure 1 shows the simulation design for scheduling the on-call physicists. The first step is to input the old data of the on-call treatment cases to our computer program running on the MATLAB platform. The data includes the identification of physicist, total number of times scheduled and total number of treatment cases in the whole on-call program. In this study, the data started in the February of 2010 and a partial sample of data (8 out of 32 on-call physicists) is shown in Table 1. The next step is to generate the probability distributions based on the on-call data. The generation of probability distribution for the number of treatment case took the sum of each occurred treatment and divided it by the total number of all treatments. Figure 2a shows the mean number of emergency treatment case per shift for the years of 2010–2017 and the variance. Figure 2b shows the probability distribution of number

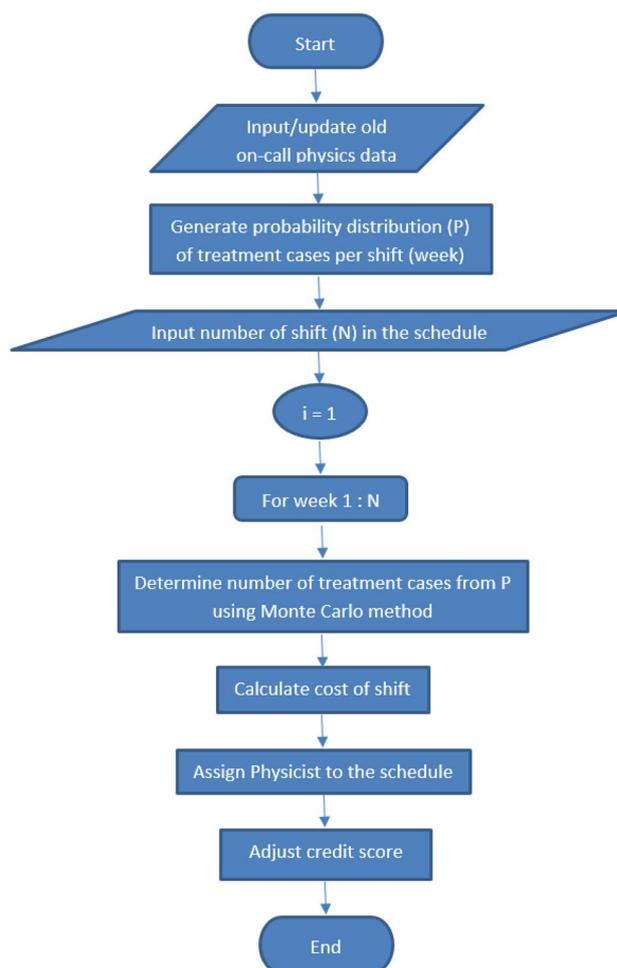


Fig. 1 Workflow of scheduling the on-call physicists using Monte Carlo simulation and the credit scoring method

Table 1 Sample of data (only 8 out of 32 on-call physicists) to be imported into MATLAB, extracted from the EXCEL data is the total number of times the physicist has been scheduled and the total number of treatment cases done over the years of 2010–2017

Physicist	Total number of times scheduled	Total number of treatment case done
1	24	49
2	17	26
3	18	26
4	15	20
5	18	24
6	15	31
7	18	28
8	17	29

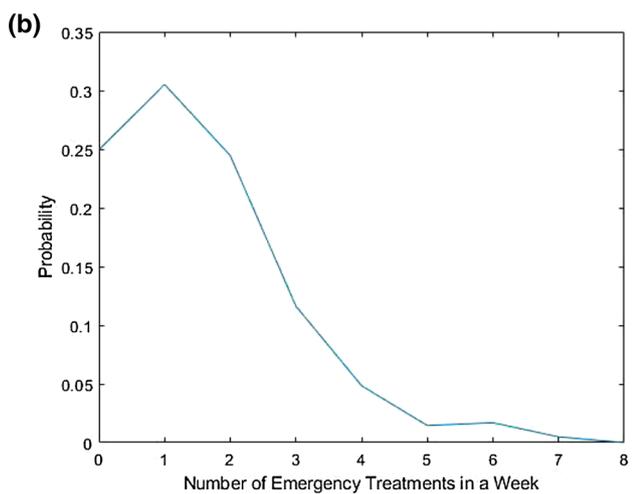
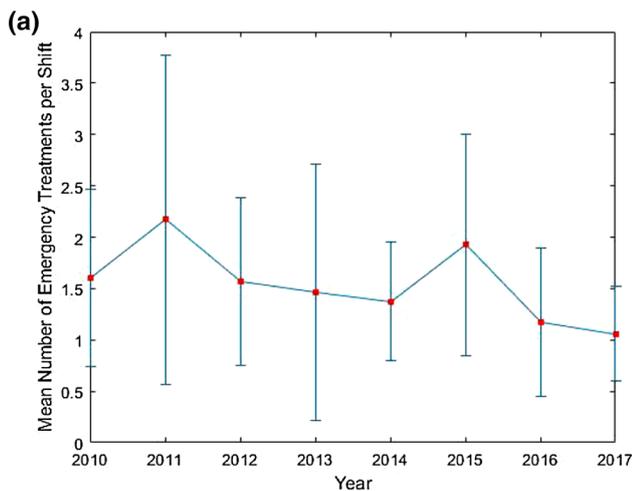


Fig. 2 **a** Mean number of emergency treatment case per shift (week) for the years of 2010–2017. **b** Probability distribution of number of emergency treatment cases per shift (week)

of emergency treatment cases per shift. In this study, the length of shift is equal to 1 week.

To set up the on-call schedule fairly, the “Most Credit First” criteria was used for queuing. In this approach, the more credit a physicist uses the lower their credit scores, the more they are pushed further back in the queue to be scheduled. In the beginning, each physicist is assigned a starting credit of 100, every time they were scheduled five credits were used up. For every treatment case carried out, the physicist used up two credits. It should be noted that credits deducted for working in the shift and every treatment case are parameters to be decided by the user considering the running of the on-call program. The parameters can further be adjusted to suit different working conditions. For example, more credits (> 2) are given to a physicist who finished a more difficult treatment case, while less credits (< 2) are given for an easier case. Once a shift is scheduled, the physicist with the most credit in the list is selected for the shift. The physicist with the most credit was found by searching the physicist array holding the credit scores of the physicists using the MAX function in MATLAB. A loop then matched the value of the credit found with the MAX function with the credit values of the physicists, and once a match was found, the physicist was scheduled for the shift. Once a physicist was selected, their corresponding credit was adjusted (Fig. 1) as per the cost of the shift. As a result, the first amount of shifts were occupied by the number of physicists needed to be scheduled in the order of queue. Table 2 shows an example scenario using the “Most Credit First” criteria. It was noted that the order of array remains static for subsequent shifts which means that if two physicists have the same credit, the physicist that appeared first in the list was the one scheduled. The process was then repeated as per the value

Table 2 Example scenario of the “Most Credit First” criteria

Physicist	Shift cost	Credit before scheduled	Credit after scheduled
1	10	100	90
2	15	100	85
3	7	100	93
4	9	100	91
5	7	100	93
6	10	93	83
5	8	93	85
4	20	91	71
1	20	90	70
2	5	85	80

The original order of the physicist is held in the cell array (Physicist “1”, “2”, “3”, “4” and “5”)

At the tenth shift physicist “2” was scheduled because they were ordered before physicist “5” in the original cell array despite both have a credit of 85

of N as shown in Fig. 1 (e.g. $N=52$ weeks for a year) based on the required amount of shifts needed to fill for a year. In Table 2, the shift cost was calculated by predicting the number of treatment case per shift using Monte Carlo simulation, based on the probability distribution in Fig. 2b. The number of on-call cases was predicted by a single random variable drawn from the probability distribution.

Evaluation of the old on-call schedule using the new scheduling method

The workload for each physicist in the shift in the old on-call schedule was compared to the one using the new method. To evaluate the workload balance among all on-call physicists, schedules from 2010 to 2017 were regenerated using the new method based on Monte Carlo simulation and the credit score approach. A physicist was considered biased if he/she was scheduled more and conducted more emergency treatment cases in comparison to other physicists. This was qualified by looking at the mean number of scheduled occurrences and mean number of treatment case worked, and the deviation from the mean (DfM) of each physicist. In this study, it was considered a scheduling bias if the DfM was greater than 30%. This is justified by our experience to achieve a good compromise taking into account various factors. The pool of physicists changed over the course of 2010–2017 and as a result only the physicists who were scheduled 10 or more times and had worked 10 or more treatment cases were considered. However, for the simulation the pool remained constant throughout, so the full list of physicists was considered.

Results and discussion

When comparing the fairness of the simulated schedules to that of the old schedules, the number of times scheduled, and the number of treatment cases worked by each physicist were justified through the DfM. A fair schedule system would imply that one should be scheduled more often if they were performing less emergency treatment cases relative to others. If a physicist is scheduled more often and performs more emergency treatment cases relative to others, then the scheduling system must have a bias towards the particular physicists. This is also true for a physicist scheduled less often and performs less treatment cases than others. Consequently, a high DfM for both the number of shifts scheduled and the number of treatment cases worked, indicated that a physicist may be working either too much or too little relative to other physicists.

Table 3 shows the fraction of DfM for the shifts and treatment cases in 2010–2017 for physicists working 10 or more shifts or treatment cases, while Table 4 shows the DfM for

Table 3 Fraction of DfM for the shifts and number of treatment cases in the years 2010–2017 for physicists who both worked or conducted 10 or more treatment cases. The physicists who had DfM for shifts or treatment cases greater than 30% are marked in bold

Physicist	Number of shifts	Number of treatment cases	DfM for shifts	DfM for treatment cases
1	24	49	0.46	0.92
2	17	26	0.03	0.02
3	18	26	0.09	0.02
4	15	20	0.09	0.22
5	18	24	0.09	0.06
6	15	31	0.09	0.21
7	18	28	0.09	0.09
8	17	29	0.03	0.13
9	17	19	0.03	0.26
10	18	18	0.09	0.29
11	13	27	0.21	0.06
12	18	31	0.09	0.21
13	18	27	0.09	0.06
14	19	31	0.15	0.21
15	12	25	0.27	0.02
16	10	14	0.39	0.45
17	18	28	0.09	0.09
18	22	38	0.34	0.48
19	18	25	0.09	0.02
20	17	17	0.03	0.34
21	16	27	0.03	0.06
22	11	18	0.33	0.29
23	10	10	0.39	0.61
Mean	16.48	25.56		

the on-call scheduling using Monte Carlo simulation and the credit score approach. The on-call physicists who had DfM for shifts or treatment cases greater than 30% are marked in bold in Table 3, while there is no physicist marked in Table 4 using the new scheduling method. It can be seen that there are six physicists (Physicists “1”, “16”, “18”, “20”, “22” and “23”) who had either DfM for shifts or treatment cases greater than 30% in the workload evaluation. In addition, there are nine physicists scheduled and worked less than 10 shifts and treatment cases, and they are not listed in Table 3. This shows that six physicists were overloaded, while nine physicists were underloaded in 2010–2017 based on the old schedule, which did not consider the workload balance of physicist. When the “Most Credit First” criteria was used in the on-call scheduling, it is seen that there is nobody having greater than 30% of DfM for shifts and treatment cases. In addition, all physicists had treatment cases more than 10 in 2010–2017 as shown in Table 4. This shows that the workload is distributed evenly among all physicists in the on-call program. This is because our new method considered

Table 4 Fraction of DfM for the shifts and number of treatment cases in the years 2010–2017 for physicists who both worked or conducted 10 or more treatment cases using the new scheduling method based on Monte Carlo simulation and the credit score approach

Physicist	Number of shifts	Number of treatment cases	DfM for shifts	DfM for treatment cases
1	12	21	0.01	0.06
2	12	20	0.01	0.02
3	12	19	0.01	0.03
4	13	20	0.09	0.02
5	12	21	0.01	0.07
6	12	19	0.01	0.03
7	11	20	0.07	0.02
8	13	21	0.09	0.06
9	13	23	0.09	0.17
10	12	19	0.01	0.03
11	13	15	0.09	0.23
12	12	17	0.01	0.16
13	11	20	0.07	0.01
14	12	19	0.01	0.03
15	13	16	0.09	0.18
16	10	24	0.15	0.22
17	10	22	0.15	0.11
18	13	19	0.09	0.03
19	12	19	0.01	0.03
20	13	15	0.09	0.23
21	14	15	0.18	0.23
22	12	21	0.01	0.06
23	11	21	0.07	0.06
24	12	19	0.01	0.03
25	9	26	0.24	0.03
26	12	21	0.01	0.06
27	12	19	0.01	0.03
28	11	20	0.07	0.01
29	12	19	0.01	0.03
30	12	17	0.07	0.13
31	10	22	0.01	0.11
32	11	21	0.01	0.06
Mean	11.84	19.68		

the workload of every physicist in term of credit score and probability of treatment case per shift predicted by Monte Carlo simulation.

The assignment of credit costs for a physicist scheduled for the shift (credit cost = 5) and treatment case worked (credit cost = 2) is based on our experience in the on-call scheduling. More or less shift and treatment case credit can be considered according to the availability of physicist in the shift (e.g. Christmas and major holidays) and the treatment case difficulty. These credit costs can also be predicted by research into stress values associated with scheduling

in healthcare. So far, little research is available to quantify these parameters into a viable credit score. Next step is to improve the credit system as more research is released in regards to stress and workflow in the healthcare environment. Future work also includes considering the probability distribution of the radiation oncologist on leave/at conference, and to use the MATLAB optimization instead of the maximum function and a loop match for the system with a larger scale.

Conclusions

For emergency radiotherapy, Monte Carlo simulation incorporating the “Most Credit First” criteria was proposed in physicist on-call scheduling to improve the workload balance of physicists in the pool. An evaluation of the old schedule in 2010–2017 found that there were 6 out of 32 physicists having on-call workload (number of shifts or number of treatment cases) greater than 30% of the mean. By using the new scheduling method, nobody has workload greater than 30% of the mean. In addition, by considering physicists who have done more than 10 shifts or treatment cases in 2010–2017, the mean numbers of shifts and treatment cases per physicist were reduced from 16.5 and 25.6 to 11.8 and 19.7, when the past data was compared to the new scheduling method, respectively. It is concluded that our proposed scheduling method can maintain a better fairness and workload balance among all physicists in the emergency radiotherapy program.

Compliance with ethical standards

Conflict of interest X Bauza and James C. L. Chow have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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