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# A philosophical approach to treatment machine maintenance and breakdown

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**Abstract.** Planned preventative maintenance (PPM), quality control (QC) checks and breakdown all contribute to the down-time of a radiotherapy treatment machine. Low levels of machine availability are unacceptable both clinically and financially. Clinical data demonstrate that, for many tumours, interruptions to treatment will result in reduced local control. Reductions to the gaps in treatment can be achieved by patient interchange between machines. Maintaining the maximum possible machine availability will reduce the potential for errors associated with the transfer of patients between machines, and reduce the cost of treatment. Practices for routine PPM and QC vary between hospitals. In this report, a rationale for breakdown and maintenance will be described. Based on the faults experienced on a Philips SL75-5 and a Philips SL25 over a period of 3 years, the workload associated with routine maintenance and quality control are presented and the additional work associated with breakdown discussed. Faults have been categorized on a scale between catastrophe and maintainability. A demonstration of how this analysis can be used to assess the cost-benefits of proposed changes in working patterns by the extension or reduction of maintenance periods is provided. The results indicated that no gain would be made in changing from a 1-day to a 2-day per month PPM schedule.

## Introduction

Within the past decade, the complexity of radiotherapy treatment machines has increased dramatically, from simple cobalt units to multimode linear accelerators with complex add-on equipment such as multileaf collimators. This increase in sophistication has allowed the introduction of a range of new treatment techniques. Inevitably, as the machine complexity has increased, there has also been an increase in the sources of potential breakdown. In addition, greater machine complexity has introduced potential hazards which were not present in the older, simpler machines [1]. These machines therefore have a higher maintenance and quality control requirement, necessitating more time spent performing measurements than was required for the simpler units.

Clinical data demonstrate that, for many tumour types, gaps in treatment result in a reduction of local control [2, 3]. Although this can be aided by the transfer of patients between machines, this is inconvenient, and introduces a potential for errors. In addition, because revenue is generated on the basis of the number of patients treated, any reduction in availability for treatment will increase the cost per fraction. Hence, there is the clinical need to maintain a high level of machine availability.

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## Quality control and planned preventative maintenance

The nature of radiotherapy treatment requires that the machines work within tight tolerances. Current recommendations state that a quality assurance programme should be set up to ensure that the performance meets the required specification [4, 5]. Two components of the overall quality assurance programme should be planned preventative maintenance (PPM) and quality control (QC) checks.

With planned preventative maintenance, a machine is routinely taken out of service and investigated for possible areas of wear and potential breakdown. This allows components to be replaced, and correct function to be established during a controlled period, rather than have the machine breakdown during use. It is now widely recognized and indeed recommended by manufacturers that PPM is a desirable activity in relation to radiotherapy treatment machines. This view is based upon experience at many centres.

QC is defined by the International Standards Organization as the process through which the actual performance is measured and compared with existing standards, and the actions necessary to keep or regain conformance with the standard [6]. QC of linear accelerators in the UK is generally specified by the document BS5724 [7] which is itself based on a document produced by the

International Electrotechnical Commission [8]. These standards specify the required mechanical, optical, field uniformity and dosimetric performance for both photon and electron beams in megavoltage equipment. However, the proposals for accuracy listed within these documents must only be considered as guidelines. The accuracy tolerances which are set for a machine within a department must be based upon the clinical requirements and the achievable machine performance. The required clinical accuracy will depend on the treatment techniques being used and the anatomical sites being treated. This can be estimated from the dose–response curves for the tissues of interest. Machine performance is also an important consideration, as there is no point in specifying tolerances which are tighter than the machine can deliver. Machine performance will vary between manufacturers, and will decrease with increasing age. Therefore, tolerances may need to be reviewed throughout the life of the machine. Consequently, treatment techniques and anatomical sites may need to be revised depending on the outcome of the review of tolerances. If the tolerances are increased, the machines may no longer be suitable for some techniques and sites.

## Machine availability

During the installation of a new machine, the physics department consider the minimum performance which will be required from the machine. At this stage, a PPM and QC programme should be set up to manage the machine maintenance and quality control. The maintenance of the machines is usually performed by either the manufacturer of the equipment, or technical staff from the hospital. It will generally be the responsibility of the physics section to decide who should perform this maintenance. In general, the hospital's physics section will also undertake the QC of the machine, irrespective of who is undertaking maintenance, and should therefore decide whether the machine is suitable for clinical use. The PPM and QC programme must ensure that the total time required for maintenance, QC and breakdown does not reduce the machine availability below a figure which is clinically and economically unacceptable. Such a figure could be calculated on the basis of the number of treatments per hour, their revenue and the cost of the equipment to run. The meanings of all figures quoted should be stated explicitly. For example, the required availability may be considered to be from 9 am to 5 pm, 5 days per week, or 24 h per day, 7 days per week. Although there is a definition of machine availability for the National Health Service (NHS), it does not deal with all of the issues which can affect the availability of modern treatment machines, and there can still be confusion over breakdown figures [9, 10].

## Treatment machine faults

Faults on treatment machines may be classified as lying somewhere between two extremes: catastrophes and maintainable. "Catastrophes" are associated with component failure, significant component deterioration or human error. These faults cannot be predicted, and will always result in a breakdown. "Maintainable faults", at the other extreme are predictable, and through routine maintenance should never cause a machine failure. "Intermediate faults" lie between these extremes and for one of several reasons, *e.g.* cost of spares, are not true catastrophes, but are likewise not maintainable. Some faults which currently exhibit catastrophes may be cost-effectively maintained. By identifying which breakdowns are caused by faults of this nature, appropriate checks can be added to the PPM programme, resulting in reduced machine down-time. However, all faults cannot be maintained, and so breakdowns will always occur and must be accommodated.

Faults may arise during clinical use, PPM or QC. Repairs take time, and it is often necessary to perform additional QC to ensure that correct function has been restored before treatment can recommence [11]. Depending on the nature of the fault, and the time of occurrence, it may be possible to schedule the repair for a time when the machine is not required for treatment. In this respect, three categories of fault response-time can be identified.

(1) Faults requiring immediate attention.

(2) Faults requiring attention sooner than a routine maintenance period, but not immediately.

(3) Faults which can be scheduled for a routine maintenance period.

With respect to the fault category extremes described above, we can see that catastrophes generally have to be attended to immediately, with the possibility of being scheduled for repair within a short time. However, maintainable faults may be scheduled for periods of routine maintenance. Table 1 summarises the relationship between the type of fault and the required response time.

In addition to the work performed during routine PPM periods and as a result of a breakdown,

**Table 1.** Relationship between fault type and required response time

| | Immediate | Soon | Scheduled |
|---|---|---|---|
| Catastrophe | √ | √ | × |
| Intermediate | √ | √ | √ |
| Maintainable | × | × | √ |

other types of maintenance may be undertaken on the treatment machines. For example, the manufacturers may have suggested an alteration to the machine which will improve performance or safety, or a new accessory may need to be fitted. Although these jobs still require the allocation of staff time, they would never be considered for scheduled PPM other than on a one-off basis. They are therefore not considered any further in this report.

## Method

This hospital has developed a practical system to record and monitor the availability, breakdown, repair and adjustment of treatment machines. It is based on the approach to maintenance and breakdown described in the previous section. Each event within the system is recorded on a separate "job card". This card records the initiation, responsibility, execution and completion of each event. As such it encompasses the entire process of the work. The department's protocol requires that transient faults during treatment must occur twice successively before they require investigation by physics staff.

### *Local machine availability, PPM and QC*

The target minimum availability at this centre is 97.5% for a simple single energy linear accelerator, and 92.5% for a complex multimode machine. This is based on the machine being required between 9 am and 5 pm, 5 days per week, except for scheduled PPM and QC time.

Each treatment machine has its own PPM and QC programme. All machine servicing is performed in-house by technical staff who have attended manufacturers' courses and the PPM schedule is based upon that recommended by Philips, but distributed throughout the year. This amounts to 1 half-day per month. QC checks are based on BS5724/IEC62C, with the necessary adjustments to suit our local techniques and machines. All accelerators have their calibration checked every morning, but this is done before the machine is required for treatment and therefore does not result in a reduction of clinical machine hours. Weekly, the SL75-5 is allocated 1 h, and the SL25 2 h for QC. In addition, both machines are allocated 1 half-day per month for quality control. Monthly checks are performed on a Friday afternoon, directly after the PPM. This allows work to continue into the weekend if required, thus eliminating any extra reduction of clinical machine time.

### *Response times to faults*

Any work which was performed as part of a scheduled PPM or QC period was considered routine work. Non-routine jobs were given a required response time at the time that the "job card" was raised. This could be one of the following: immediate, within 24 h, within 1 week, within 1 month, or other. This last category covers jobs for which no time scale was specified, or which were scheduled to be done on a specific date, *e.g.* a gun filament change.

### *Performance/maintenance job classification*

Each job was classified retrospectively as being either performance-related or maintenance in nature. Performance-related jobs were those which stemmed from a concern over either the machine's running performance, or some aspect which may have affected the dosimetric performance of the machine. In general, the performance-related jobs stemmed from some aspect of the machine which required setting up. For example, adjustments to overcome the slow rise of output at beam-on, and adjustments to improve the alignment of the X-ray and light fields would both be classified as performance-related. Jobs which were classified as maintenance work were associated with some sort of breakdown. For example, replacing a contactor would be classified as purely maintenance work. However, there are cases where the classification depends on the underlying problem. One example would be where the beam symmetry was found to be out of tolerance. In this case, the classification of the work would depend on the cause of the deterioration in performance. For example, if a bending coil had failed it would be classified as maintenance, but if it was merely a routine adjustment, it would be classified as performance.

### *Maintainable/non-maintainable faults*

Jobs which were classified as maintenance were further categorized retrospectively as being either maintainable, possibly maintainable, or not maintainable. Maintainable faults are those which have occurred in the past, but which could have been prevented by including additional checks in the PPM schedule. An example of this type of fault would be an accessory code interrupt which was caused by dirty connectors on the electron applicators. Non-maintainable faults cannot be predicted, and will therefore always result in some down-time for a machine. One example would be a transistor failure on a signal conditioning board. Possibly-maintainable faults are those which may be predicted, but for which nothing is currently done before a breakdown for one of four reasons. These are as follows.

(1) The component is easy and quick to repair upon failure, so little would be gained. An

example would be a distance meter lamp failure.

(2) The component is too expensive to replace until it has failed, *e.g.* a magnetron.

(3) It would be too expensive and time-consuming to change the component routinely from a PPM point of view, *e.g.* the potentiometers which produce the field size and gantry angle readouts.

(4) Not enough information is currently known about the best time to replace the component, *e.g.* the ion chamber or the thyratron. However, it may be that in the future more information about these components will have been gained, allowing a scheduled replacement of the component and thereby eliminating down-time due to faults of this nature. We have already achieved this for our gun filaments which are now removed at the end of their useful life, shortly before failure.

## Results

### *Difference in performance and maintenance workload between machines*

The figures presented are based upon current working practices at this hospital, and the statistics which have been collated regarding the availability, breakdown and repair of a Philips SL75-5 single energy and a Philips SL25 computerized multimode linear accelerator. The data, which have been collected over a period of 3 years, are based on the written records which have been made following any work done on a machine. Figure 1 shows the number of man-hours spent on machine performance and maintenance work between January 1993 and December 1995. This corresponds to the machines' 7th, 8th and 9th years of an estimated 12 year life. It is immediately noticeable that the multimode machine required considerably more work than the simple machine. In fact, the workload is 3.2 times that of the simple machine. The difference in relative proportions of performance and maintenance work between the machines was due almost entirely to one job on the SL25 which required 182 man-hours. Removing that job from the graph, the proportions for the SL25 change to 30.1% performance and 69.9% maintenance, which is similar to the SL75-5. This fault was in fact due to a component which the manufacturers did not stock, and therefore had a 9 week lead time. If we consider that this fault would occur once at most within the lifetime of the machine, for the purpose of this analysis we could be justified in spreading its effect over the estimated life of the machine (12 years). In this case, the workload would be 2.7 times that of the simple machine.

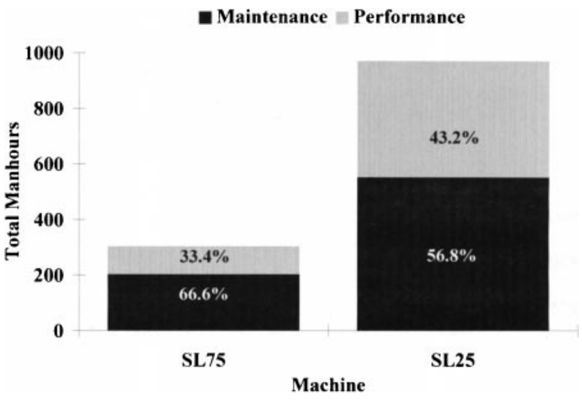


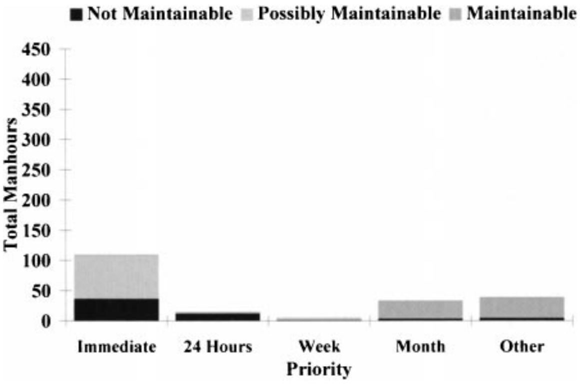

**Figure 1.** Total unscheduled man-hours worked on SL25 and SL75, 1993–1995.

### *Maintainability of faults*

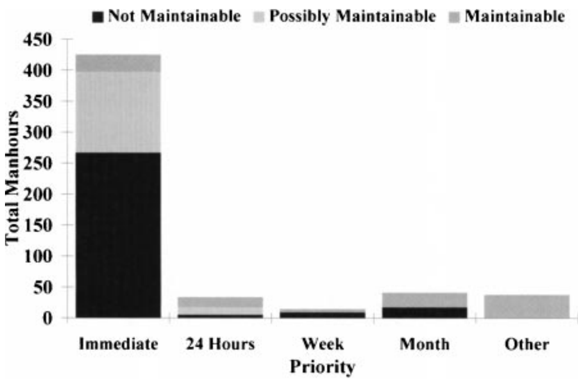
Figure 2 summarises the retrospective analysis of how maintainable each fault was. Figure 2a shows the data for the SL75-5, and Figure 2b, the SL25. Again, the difference in total workload is apparent. For both machines, the "Immediate" category contained the largest percentage of man-hours, with 54% of the work on the SL75-5 and 77% of the work on the SL25 occurring in this category. The difference in the percentage of work in this category was found to be mainly due to the larger amount of control circuits required to change energies on the multimode machine, and the larger power required in the high tension (HT) circuits to achieve the higher energies. The small percentage of work in the "Immediate" category which has been classified as "Maintainable", 1.6% for the SL75-5 and 6.6% for the SL25, indicates that PPM is largely being undertaken in the correct areas. However, all categories do still have a Maintainable component, and scheduling of tests associated with these faults should reduce machine down-time. The large Maintainable component of the "other" category for both machines is associated with gun filament changes which are scheduled in advance for PPM time.

### *Man-hours associated with maintenance and performance work*

After a machine fault has been repaired, it is often necessary to set the machine up and check its performance before treatment may recommence. Figure 3 demonstrates the percentage of each maintenance category which has been found to be associated with performance checks and set-up on the SL25. The checks discussed here are in addition to the time spent on performance-related jobs discussed previously. It is noticeable that the set-up and performance checks form a higher percentage of the maintenance time for jobs which are in



(a)



(b)

**Figure 2.** Unscheduled maintenance man-hours on (a) SL75 and (b) SL25.

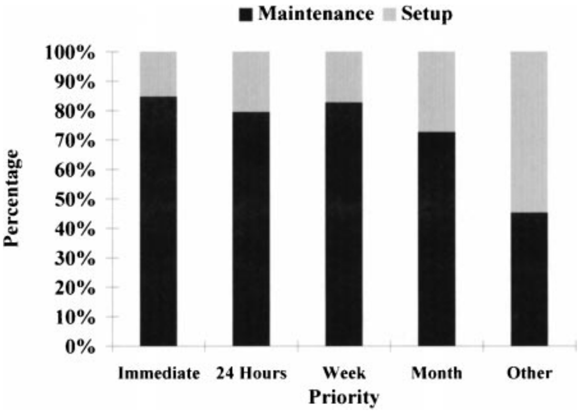



**Figure 3.** Percentage of maintenance time attributed to set-up.

the "other" category. In fact, set-up forms 55% of this category, compared with 27% or less for the remaining categories. The reason for this is that non-urgent jobs with a high set-up requirement, such as a gun filament change tend to be scheduled for a specific date.

### *Assessment of extended PPM*

In any comparative evaluation of the use of medical equipment, the balance between cost and benefit requires very careful consideration. Quantification of the cost and the benefit by a parametric or non-parametric method assists comparisons to be made. In estimating the total financial amount required to provide a new facility or technique, the importance of its impact on staff workload and its impact on the clinical service or other clinical services should not be forgotten. Some level of priority should be given to the various costs, as it may not be possible to parameterize them identically, or even parameterize them at all. Similarly, the benefits may be seen in the financial costs saved, but again the benefit may not be financial and hence may not even be quantifiable. Clearly, no single cost or benefit parameter alone should be the deciding factor, and several approaches and aspects can and should be considered. In the following example, consideration is given to the simple financial balance between the benefits of increasing planned maintenance and the loss of treatment capacity. It should be recognized, however, that other aspects such as clinical availability and likelihood of interruptions during treatment, or other aspects may take a higher priority in the overall decision.

Using the data from the review, it is estimated that a 2-day PPM schedule for the SL25 would save £9110 by the reduction of payments for out-of-hours work, but would cost £16 511 due to the reduction in hours available for treatment. The net result would therefore be a loss of £7401. Similarly, for the SL75 a saving of £7580 would be made, but the reduction in income would cost £20 045 resulting in a loss of £12 465. For the purpose of the calculation the number of fractions treated per hour and the cost per fraction have been taken from a review of linear accelerator capacity [12]. Cost per man-hour is based on the nominal current rates charged by manufacturers for service contracts. The results indicate that changing to a 2-day PPM schedule is not a financially viable option for either machine, and would result in a larger loss for the simpler machine which requires less maintenance. Details of the calculation are given in the Appendix.

## Conclusions

A rationale has been presented to categorize objectively and assess PPM/QC. Application of the technique to a real department has been demonstrated. From the data obtained, we have found that a large proportion of the jobs are undertaken in the "Immediate" category. Most of the jobs which were categorized as maintainable were already in the "month" or "other" categories, and represented jobs such as scheduled gun replacements. Few faults which have occurred could be realistically made Maintainable, and this therefore leaves a substantial amount of work which must still remain unscheduled. On this basis alone, it seems unlikely that an increase in planned preventative maintenance would be beneficial. To confirm this, the method has been extended to examine objectively an increase in PPM by a simple cost–benefit analysis. No account has been taken of additional costs from other staff groups, or of the possibility of treating patients on another machine during service. On the basis of the results presented, there was no cost-benefit justification for an increase in scheduled PPM time for the two machines considered.

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**Appendix**

Example calculation based on the data collected for the SL25.

Total annual man-hours scheduled for 1PPM session: 90.
Total annual man-hours used for PPM: 144.
Total annual overtime man-hours for PPM: 54.

From data:
Mean annual unscheduled maintenance man-hours: 183.8.
Unscheduled maintenance man-hours classified as maintainable: 37.1.
Maintainable faults = 20.18% of maintenance man-hours and 79.82% = not maintainable.

Current breakdown rate = 4.8%.
If maintainable faults removed by extra PPM:
breakdown rate = $0.7982 \times 4.8\% = 3.8\%$ and
Unscheduled maintenance man-hours = $183.8 - 37.1 = 146.7$.

Total annual machine hours = 1902.
1 PPM slot = 45 h/year = 2.4%.
2 PPM slots = 90 h/year = 4.8%.

Total down-time (1 PPM slot) = $2.4\% + 4.8\% = 7.2\%$.
Total down-time (2 PPM slots) = $4.8\% + 3.8\% = 8.6\%$.
Change in availability = $8.6 - 7.2 = 1.4\%$ = 26.63 h/year.
Assuming 6.2 fractions/h and £100 per fraction, this would result in a loss of £16 511.

Change in man-hours = $183.8 + 54 - 146.7 = 91.1$.
Assuming £100 per man-hour, this reduces costs by £9110.

Balance = £9110 − £16 511 = −£7401.