Relative costing of analytical systems

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Introduction

Within the last two to three years most hospital departments in the British National Health Service (NHS) have been required to operate within a fixed budget, the preparation of which can be very complex in departments with employees of diverse function and expertise. There is also an increasing demand that the NHS should examine the cost effectiveness of its service; similar demands are being made in other countries. Therefore, a department with a specific function should know the cost of its service, and adjust its budget with strict regard to the quality of cost efficiency of the service.

In 1975 the British Department of Health and Social Security (DHSS) commissioned the preparation of a document outlining a scheme for the "total costing" of a pathology laboratory [1]. Costing exercises in clinical chemistry have since been based on this on this rather complicated scheme or have been concerned solely with the operation of a particular instrument. The latter analysis is often superficial, taking into account only the cost of reagents. If carried out by the manufacturer, the methods of cost analysis can be obscure and difficult to apply to a particular laboratory's workload or to the comparison of the performance of similar instruments marketed by different manufacturers. As capital and running costs of instruments increase it becomes more important to know the relative costs of carrying out analyses by alternative instrumentation before purchasing new equipment.

This study describes a new approach to costing the workload of a hospital laboratory which is less complex than the total costing scheme of Coopers and Lybrand [1]. The scheme presented provides a facility for costing a defined laboratory workload on different instruments, and hence it is referred to as Relative Costing of Analytical Systems (RCAS). It takes into account those costs which are likely to arise in normal circumstances and vary between instruments.

If the workload is made up of a sufficiently broad spectrum of analyses, then not only the costs of single instruments of similar capacity, but also those of combinations of instruments of different capacity can be compared. Such combinations are referred to as systems. It is essential that the workload is defined before RCAS is applied, and for the costing to be meaningful the group of analytes under consideration must constitute a sufficiently large part of the workload. In theory, costing can be carried out on a smaller workload, but in practice this is more difficult as data would have to be corrected to allow for work sharing of instruments, manpower, and in some cases disposables and reagents. Certain assumptions have to be made which must be clearly defined at the outset; they must not invalidate the costing.

The principles of the cost analysis

The analysis is divided into two parts:
(i) costing of individual instruments
(ii) use of this data to cost different analyitical systems

Individual instruments

The costing of instruments and their analyses includes all items of expenditure which are not part of the fixed laboratory overheads. These are considered under capital cost, maintenance, manpower, services, control and standardising materials, disposables and reagents.

Costings are calcuated in three categories:—
(a) Costs associated with the instrument regardless of the magnitude or complexity of the workload.
(b) Costs related to batches of analyses.
(c) Costs related to individual specimens.

Each item of expenditure is assessed in the most appropriate category, for example, capital costs are assessed in category (a) and reagent costs in category (c). The appropriate category for other items cannot be specified as it will vary from one instrument to another. When the analysis is complete, two sets of data are available for each instrument, the expenditure related to the instrument ie the sum of the costs in category (a); and expenditure related to the workload ie the sum of the costs in categories (b) and (c).

Analytical systems

The cost of an analytical system is the sum of the costs of the individual instruments included in the system, ie all the expenditure in category (a) and the expenditure in categories (b) and (c) which correspond to the appropriate parts of the workload. The cost per test is not a fixed sum for an analyte measured by a particular instrument, but is influenced by the way the instrument is used, that is, if the instrument is used to measure this particular analyte only, or in combination or alternation with other analytes.

The overheads excluded from RCAS include personnel indirectly involved with the instrumentation such as senior medical, scientific and technical staff, process workers and secretarial staff, also laboratory overheads such as building costs, heating, lighting, telephone etc.

Workload

The annual workload of the Clinical Chemistry Department at Northwick Park Hospital has been chosen as a model for

Table 1. Annual workload model

Analyte	Batched	Non batched	Total
Acid phosphatase	564		564
Albumin	42,684		42,684
Alkaline phosphatase	28,346		28,346
Amylase	2,052	156	2,208
Aspartate transaminase	28,452		28,452
Bicarbonate	8,232	2,184	10,416
Bilirubin (total)	25,404	240	25,644
Bilirubin (conjugated)	276	204	480
Calcium	29,580	924	30,504
Chloride	1,392		1,392
Cholesterol	10,848		10,848
Creatine kinase	8,736		8,736
Creatinine	11,628	36	11,664
Gamma glutamyl transferase	2,604		2,604
Glucose	21,732	1,404	23,136
Iron	8,064		8,064
Iron binding capacity	8,064		8,064
Lactate dehydrogenase	612		612
Phosphate	28,056		28,056
Potassium	54,984	3,264	58,248
Sodium	54,984	3,264	58,248
Total protein	42,540		42,540
Triglyceride	2,472		2,472
Urate	11,928		11,928
Urea	53,004	2,772	55,776
Multichannel profile	45,252		45,252

the application of RCAS as it is typical for an average sized district general hospital. It was determined on the basis of a detailed study of the analytical data for one month. Work dealt with during the normal working hours is referred to as batched analysis while emergency requests made out of normal working hours are handled separately and referred to as non-batched analyses. For the purpose of RCAS it is assumed that non-batched analyses are carried out as separate, single assays, but samples assayed on Saturday or Sunday mornings are included among the batched analysis workload.

Table 1 contains a list of the analytes considered suitable for inclusion in the study. At least 40 requests were received for each per month and the methods chosen were all capable of being automated. They were measured by the 'kinetic' or 'end point' type of analysis employed in the particular instruments included in the study. Therefore, thyroxine, oestrogen, cortisol and 5'-nucleotidase had to be excluded from the list, but can be subjected to a separate RCAS analysis. Conjugated bilirubin was included because of the measurement of total bilirubin although its rate of analysis was less than 40 per month.

Reagent costing

The number of methods per analyte has been limited to two for simplicity. Ideally one method should be costed per analyte but this is only possible if the method is applicable to all the instruments under consideration. However, different instruments sometimes require chemically different methods to measure end-point and the rate of reaction of the same analyte. By restricting consideration to two methods, those chosen may not always have been ideal for each instrument but the costing of the reagents is rendered as comparable as is possible for all the instruments.

Reagent costing was based on bulk buying of reagents and kits at prices quoted for the last quarter of 1978, and in quantities appropriate for the workload. The major suppliers were BDH Chemicals Ltd, Poole, England; Clin Tech Ltd, London SE18 5TF and Boehringer Corporation (London) Ltd, Lewes, England. The proportional quantities of each reagent required in a particular routine method were calculated and the cost per litre of the final reagent mixture determined.

It has been assumed that the identity and relative quantities of the constituents of each final reagent mixture are invariant with respect to different instruments. This assumption is not completely valid, but when the cases with deviations were investigated, the differences in the individual costs of the constituents did not significantly change the cost of the final reaction mixture. The final reagent cost for each method considered is given in Table 2. Some analyses require a blank determination to be carried out and where this involves different reagents the appropriate cost has been calculated separately. This approach to costing does not apply to instruments for which use of the manufacturer's reagents and kits is obligatory eg the Du Pont ACA.

Manpower

In RCAS only the manpower used in operating the analytical instruments is taken into account. This includes the time that would normally be spent by the operator in day to day maintenance. It is assumed that operating the type of instruments included in this study does not influence intra laboratory requirements in expertise and times of employment of other personnel who do or do not contribute to the processing of specimens.

Manpower costing has been determined in two ways according to the type of instrumentation. Annual costing is used for non-selective multichannel instruments where, assuming the personnel are employed full time on such analyses, the manpower is unaffected by the number of analytes determined. With the smaller instruments whose usage and hence manpower utilisation is affected by the

number of analytes measured, hourly costing is applied. The unit time cost has been calculated on the mean salary of the Medical Laboratory Scientific Officer (MLSO) for the last quarter of 1978 plus 20% to cover national insurance and superannuation etc. Calculation of the hourly rate is based on a 37 hour, 5 day week and adjusted for holidays and a 13% deduction for non productive time, ie time not spent on the actual processes of measurement. The following data are derived:—

Mean annual MLSO salary (for last quarter of 1978)	£3,970.50
20% (insurance, superannuation)	£794.10
Total annual manpower cost/person	£4,764.60
Calculation of hourly rate:—	
Number of working days (52 x 5)	260 days/annum
Annual leave	20 days/annum
Bank holidays	8 days/annum
Statutory holidays	2 days/annum
Total days lost	30 days/annum
True number of working days	230 days/annum
Number of working hours 230 x $\frac{37}{5}$	1,702 hours/annum
13% non productive time	221 hours/annum
Net number of working hours	1,481 hours/annum
Hourly rate $\frac{4764.6}{1481}$	£3.22/h

In the case of the non-batched analysis, manpower is covered by a fixed "on-call" payment which is irrespective of the number of analyses carried out and the type of instrument used; it is therefore excluded from this costing. The

Table 2. Final reagent cost

Analyte		Method	Cost (pence/1)
Acid phosphatase	I	Nitrophenyl phosphate	372.7
Albumin	I	Bromocresol green	38.0
Alkaline phosphatase	I	King and Kind	24.2
		Blank	21.1
	II	Nitrophenyl phosphate	4770.0
Amylase	I	Starch/iodine	8.2
Aspartate transaminase	I	NAD/NADH	4036.0
		Blank	4036.0
Bicarbonate	I	Cresol red	2.0
	II	Carboxylase	2491.0
		Blank	40.6
Bilirubin	I	Diazo Michaelsson	59.9
Calcium	I	Cresolphthalein	50.7
Chloride	I	Thiocyanate	11.7
Cholesterol	I	Cholesterol oxidase	6632.0
	II	Leibermann-Burchard	251.1
Creatine kinase	I	NAD/NADH	23810.0
	II	Diacetyl/orcinol	6414.6
Creatinine	I	Jaffe	17.8
		Blank	0.8
γ-Glutamyl transferase	I	NAD/NADH	6633.0
		Blank	6633.0
Glucose	I	Glucose oxidase	108.5
Iron and I.B.C.	I	Ferrozine	59.4
Lactate dehydrogenase	I	NAD/NADH	3800.0
		Blank	24.7
Phosphate	I	Stannous chloride	54.9
Sodium and potassium	I	Flame photometry	1.2
	II	Ion selective electrode	479.0
Protein	I	Biuret	25.2
		Blank	20.6
Triglyceride	I	NAD/NADH	11923.0
		Blank	9200.0
Urate	I	Uricase	29.0
		Blank	135.5
	II	Phosphotungstate	386.6
Urea	I	Berthelot	103.4
	II	Diacetyl monoxime	51.0

manpower costs for Saturday and Sunday mornings are also covered by "on-call" payments. However, the magnitude of the workload at these times is such that it was costed as batched analysis.

Other costs
The costs other than those of reagents and manpower will be considered here under the appropriate sub-headings.

Capital and depreciation
The capital cost of an instrument needs to be included and should be spread uniformly through its expected working life. The DHSS recommendation of seven years average life [1] has been used and depreciation has therefore to be calculated as one seventh of the capital cost per annum. To this has to be added the cost of the maintenance contract, which usually stipulates that the instrument be maintained under warranty, free of charge for the first year. Therefore, the total annual depreciation has been calculated as one seventh of the capital cost plus six sevenths of the annual maintenance contract. The latter is usually quoted as a percentage of the capital cost.

Data processing
The data handling capability of instruments varies greatly and is reflected in their capital cost and manpower requirements for data transfer. This has been allowed for by setting a minimum data processing requirement for each instrument; this is the ability to interface with a computer capable of handling the laboratory's workload. When this requirement is not met by the instrument an addition is made to the capital cost to cover suitable interfacing equipment.

Services
The services included are electricity, water and gas. Electricity and water are calculated as a product of the estimated mean consumption of the instrument and the local cost per unit, which gives only an approximate cost as the mean consumption cannot be calculated accurately. Water cost is negligible and is ignored in almost all cases except multichannel instruments fitted with a laundry system. Where the water consumption is high the cost of deionising resin is significant and has been included. Gas requirement is solely that of propane for flame photometry. Its cost has been based on purchasing large cylinders appropriate to the size of the workload.

Commercial sera
Commercial sera used for calibration and control of analyses vary from one laboratory to another and therefore it is difficult to make a generalised statement concerning their cost. The cost calculated here was based on the following assumptions:—
(i) All calibration is carried out using assayed commercial sera.
(ii) Unassayed commercial sera are used for all quality ‎control procedures.
(iii) Quality control specimens are included at the frequency of 1 in 20 for batched analyses and at a frequency of 1 to 1 in non-batched analyses, unless a more appropriate frequency is dictated by the instrument.
(iv) The volume of serum used is approximately 10% in excess of the volume required for the assay.
Costing is based on the mean price of preparations purchased in quantities appropriate to the workload. The case where a special serum was required for a particular instrument is dealt with in the section on instrumentation.

Disposables
These include blood tubes for the transportation of specimens, vials for introducing the specimen into the instrument, and any accessories associated with the analyser which need

Table 3. Instrument associated costs of Vickers M—300

Category	Details		Annual cost (pounds)
Capital	Capital cost	£125,000	26,428.57
	Maintenance 8% after 1 yr Capital depreciation $(\frac{125000}{7} + 125000 \times \frac{8}{100} \times \frac{6}{7})$		
Manpower	3 full time personnel at £4,764.60/person		14,293.80
Analysis data	Number of specimens/annum	45,252	
	Number of standards and controls	70/d	
	Total number of assays/annum (45,252 + 70 x 260)	63,452	
	∴ Total analysis time/annum $(\frac{63452}{300})$	211.5h/annum	
	Run up time	2 h/d	
	Run down time	0.5 h/d	
	Total running time/annum (211.5 + (2+0.5) x 260)	861.5 h/annum	
Services	Mean electrical consumption	15 KVA/h	
	Annual cost (consumption x rate x running time) $(15 \times \frac{1.865}{100} \times 861.5)$		241.00
	Water consumption	60l/h	
	Annual cost (consumption x rate x running time) $(60 \times \frac{0.0117}{100} \times 861.5)$		6.05
	Annual cost deionisation resin		624.00
	Annual gas consumption	6 units	
	Annual cost (6 x 5.50)		33.00
Commercial sera	Unassayed serum consumption	90 ml/d	
	Annual cost (unit cost x consumption) $(\frac{10.4}{100} \times 90 \times 260)$		2,433.60
	Assayed serum consumption	12.5 ml/d	
	Annual cost (unit cost x consumption) $(\frac{15.0}{100} \times 12.5 \times 260)$		487.50
Disposables	Mean vial cost	9p ea	
	Annual vial cost (unit cost x total assays) $(\frac{9}{100} \times 63,452)$		5,710.68
	Blood tubes cost (unit cost x number used) $(\frac{2.64}{100} \times 45,252 \times \frac{40}{100})$		477.86
		Total	50,736.06
Additional analyses	Standards and controls	70/d	
	Annual analyses (70 x 260)	18,200	
	Reagent priming time	24 min/d	
	Annual priming time $(\frac{24}{60} \times 260)$	104 h	
	Equivalent number of analyses for purposes of reagent costing (104 x 300)	31,200	
	Total additional analyses (18,200 + 31,200)	49,400	
	Effective annual workload (workload + additional analyses) (45,252 + 49,400)	94,642 VI	

replacing at regular intervals, for example pump tubes and dialyser membranes in continuous flow equipment. Vials are usually peculiar to the instrument and are therefore costed individually. In determining the number required, allowances must be made for the controls and the standards, as well as for the specimens. Blood tube cost is based on that of plain glass 10 ml tubes purchased at a bulk rate appropriate to the workload, the consumption being based on one tube for every four tests, reflecting a test/request ratio of 4:1 which the DHSS suggest is the national average [2]. This figure is not used for the multichannel non-selective instruments where it is assumed that one tube is used for each profile. No allowance is made for special tubes required for certain tests, for example glucose.

The cost of disposables such as chart paper, request and result forms are assumed to be invariable within a laboratory irrespective of the equipment, and therefore have been omitted.

Instrumentation

Ten different types of instrument have been selected for cost analysis. As stated previously, reagents have been costed per unit volume of the final mixture and the reagent cost for an instrument is based on the volume it consumes. All other expenses are calculated to assess the total running cost per annum of the individual instrument. A common costing pattern is used for all instruments, although its application varies with the differences in the individual modes of operation. For example an item may have to be classified as an overhead with one but not necessarily with another.

Consequently a series of formulae are derived for each instrument, two examples of which may be seen in Tables 3 and 5. From these data a total overhead cost is determined and a total assay cost per analyte per annum is calculated. The latter is determined for batched analyses and non-batched ones where applicable.

In the case of some of the newer instruments data were not available at the time of compilation for all of the potential analyses, and these analyses have therefore been omitted.

The costs of the materials and services are based on information which was correct at December 1978 and which are common to all instruments, they are shown below.

Electricity	1,8651p/KVA
Water	0.117p/l
Gas	£5.50/unit
Unassayed commercial sera	10.4p/ml
Assayed commercial sera	15.0p/ml
Blood tubes	2.64p/ea
Blood tube cost per test on the basis of 4 tests per tube (where applicable)	0.66p/test

The costs of other materials which are required specifically for certain instruments are accounted for individually.

Two examples of costing have been given in Tables 3 to 6 which demonstrate two extremes of approach. The Vickers M300 multichannel analyser is a profiling instrument and most of its costing is related to the instrument rather than the workload, whereas the converse is true for the Union Carbide Centrifichem 400.

Table 4. Analyte associated costs of Vickers M-300

	Method	Sample volume (µl)	Reagent volume (ml)	Reagent cost/1 (pence)	Cost/test (pence)	Total cost (pounds)
Column	I	II	III	IV	V	VI
Derivation	see Table 2			see Table 2	$\frac{III}{1000} \times IV$	$\frac{V}{100} \times 94652$
Acid phosphatase						
Albumin	I	7	3.50	38.0	0.133	125.89
Alkaline phosphatase	I	58	3.50	24.2	0.0847	80.17
Blank	I	58	3.50	21.1	0.0738	69.86
Amylase						
Aspartate transaminase	I	58	2.50	4036.0	10.090	9550.39
Blank	I	58	2.50	4036.0	10.090	9550.39
Bicarbonate	II	3	2.50	2491.0	6.2275	5894.44
Blank	II	3	2.50	40.6	0.1015	96.05
Bilirubin (total)	I	133	3.50	59.9	0.2097	240.10
Bilirubin (conjugated)	I	133	3.50	59.9	0.2097	240.10
Blank	I	133	3.50	59.9	0.2097	240.10
Calcium	I	30	3.50	50.7	0.1775	169.30
Chloride	I	3	3.50	11.7	0.0410	38.80
Cholesterol	II	58	2.50	251.1	0.6278	594.22
Creatine kinase						
Creatinine	I	133	3.50	17.8	0.0623	58.98
Blank	I	133	3.50	0.8	0.0028	2.65
Gamma glutamyl transferase	I	58	2.50	66330.0	16.5835	15696.66
Blank	I	58	2.50	66330.0	16.5825	15695.66
Glucose	I	20	4.00	108.5	0.4340	410.78
Iron						
Iron binding capacity						
Lactate dehydrogenase	I	25	3.50	3800.0	13.3000	12588.72
Blank	I	25	3.50	24.7	0.0865	81.87
Phosphate	I	17	3.50	54.9	0.1922	181.91
Potassium } Sodium }	I	15	3.60	1.2	0.0043	4.06
Total Protein	I	33	3.50	25.2	0.0882	83.48
Blank						
Triglyceride						
Blank						
Urate	I	20	3.40	29.0	0.0986	93.33
Blank	I	20	3.40	135.5	0.4607	436.07
Urea	I	4	3.50	103.4	0.3619	342.55

The results of cost analyses carried out on ten different instruments are shown in Table 7.

Systems costing
Different instruments and/or multiples of the same instrument used in combination to process a defined workload are referred to as systems. The costing of a system is carried out by summing the relevant individual instrument costs as in Table 7. A number of examples of systems costings are given below.

Workload/cost comparison
The analytes included in the batched workload shown in Table 1 have been rearranged according to the magnitude of the workload commencing with the largest. Each is then costed for each applicable instrument and these costs which are cumulative, are summed. Figure 1 shows the results of this costing procedure diagramatically. The point at which the plot meets the abscissa represents the instrument associated costs. Thus the expensive multichannel instruments have poor cost effectiveness at low workloads, although in this case it is low because not all the channels are in use. With the smaller instruments a point is reached where no more work can be handled during the normal working day and so an additional instrument is required with an additional increase in capital expenditure. Therefore, it is necessary to determine the analysis time and the total time available during the normal working day. The latter has been calculated as follows:—

Number of working days (52 x 5)	260 days/annum
Bank holidays	8 days/annum
Statutory holidays	2 days/annum
Total days lost	10 days/annum

Table 5. Instrument associated costs of Union Carbide Centrifichem 400

Capital	Capital cost	£37,500	Annual Cost (pounds)
	Maintenance 8% after 1 yr Capital depreciation $(\frac{37.500}{7} \times 37,500 \times \frac{8}{100} \times \frac{6}{7})$		7,928.57
Manpower	1 Full time operator at	£3.22/h	
Analysis data	Analysis time	variable	
	Total number analyses/rotor	29	
	Priming reagent volume	None	
	Plate changeover time	10 min	
	Plate sampling time	4 min	
Services	Electrical consumption	4.8KVA/h	
	Cost (consumption x rate) (4.8 x 1.865)	8.952p/h	
	Laundry water + deionising resin	1.3p/l	
	Methanol	55p/l	
Commercial sera	Unassayed serum consumption	100μl/test	
	Cost (unit cost x consumption) $(10.4 \times \frac{100}{1000})$	1.04p/test	
	Assayed serum consumption	100 μl/test	
	Cost (unit cost x consumption) $(15.0 \times \frac{100}{1000})$	1.5p/test	
Disposables	Analyser cups	0.55p/ea	
	Blood tubes (4 tests/tube) $\frac{(2.64)}{4}$	0.66p/ea	
		Total	7,928.57
Batched analysis	Reagent usage/rotor (2 unassayed sera + 2 assayed sera + 25 specimens) (Reagent volume + 16% reagent volume) Corrected reagent cost/test		
	cost/test + 16% cost/test		VI
	Total analysis time/rotor (2 unassayed sera analysis time + 2 assayed sera analysis time + 1 blank analysis time + 25 specimen analysis time + 10 min changeover + 4 min sampling time) Corrected analysis time/specimen		
	Analysis time + 20% analysis time + $\frac{14}{25}$ min		X
	Total manpower cost (unit cost x total running time) (3.22 x total running time) Total electrical cost (unit cost x total running time) $(\frac{8.952}{100}$ x total running time)		

Batched analysis (cont'd.)	Manpower/electrical cost $(3.22 + \frac{8.952}{100})$ total running time 3.31 x total running		XI
	Rotor costs (25 specimens) (2 assayed sera + 2 unassayed sera + 29 analyser cups + 25 (¼) blood tubes) (1.5 x 2 + 1.04 x 2 + 0.55 x 29 + 0.66 x 25) 37.53p/ rotor Rotor cost/specimen		
	$\frac{37.53}{25}$ 1.50121/specimen		XII
	Laundry cost/rotor Water + resin (100 ml)	0.13p/rotor	
	Methanol (40 ml)	2.2p/rotor	
	Water + resin + methanol	2.33p/rotor	XXII
	Cost/specimen $\frac{2.33}{25}$ 0.0932p/specimen		XXII
Non batched assays	Reagent usage/specimen (2 assayed sera + 1 unassayed serum + specimen) Reagent volume + 300% reagent volume) Corrected reagent cost/test		
	cost/test x 4		XV
	Total analysis time/specimen (2 assayed sera analysis time + 1 unassayed sera analysis time + 1 blank analysis time + 1 specimen analysis time + 10 min changeover) (sampling time is excluded as rotor is only partially filled) Corrected analysis time/specimen		
	analysis time x 5 + 10 min		XIX
	Manpower cost not applicable Total electrical cost (unit cost x total running time)		
	$\frac{8.952}{100}$ x total running time		XX
	Rotor cost/specimen (2 assayed sera + 1 unassayed serum + 4 analyser cups + 1 (¼) blood tube) (1.5 x 2 + 1.04 + 0.55 x 4 + 0.66) 6.9p/specimen Laundry cost/rotor For non batched analysis the cost/rotor and cost/specimen are the same, i.e. 0.0932p/specimen		

True number of working days   250 days/annum

Number of working hours (250 x $\frac{37}{5}$)   1,850 h/annum

13% (non productive time)   240.5 h/annum

Maximum analysis time   1,609.5 h/annum

In Figure 1 the points of discontinuity of some graphs indicate the stage where an additional instrument is required. The points of inflection occur where the analyte associated costs are higher than the average for that instrument.

Multichannel instruments

The total cost of running each of the four multichannel instruments at full capacity is compared. Except for the Hycel-M none of these is capable of analysing the complete workload model and therefore a suitable selection of analytes is made as shown in parenthesis below. For the SMAII system, costing is based on a 16 channel instrument including a flame unit. Costs are as follows :-

Vickers M-300   £78,405.90   (Albumin, alkaline phosphatase, aspartate transaminase, bicarbonate, total bilirubin, calcium, chloride, creatinine, glucose, phosphate, potassium, sodium, total protein, urate, urea)

Key to Figure 1.		
— — — — —	Hycel M	
··············	Technicon SMAII (6 channels)	
— — — —	Technicon SMAII (16 channels)	
▬▬▬▬	Technicon AAII	
— — — — — —	Coulter Kem-O-Mat	
▬▬▬▬▬	Abbot VP	
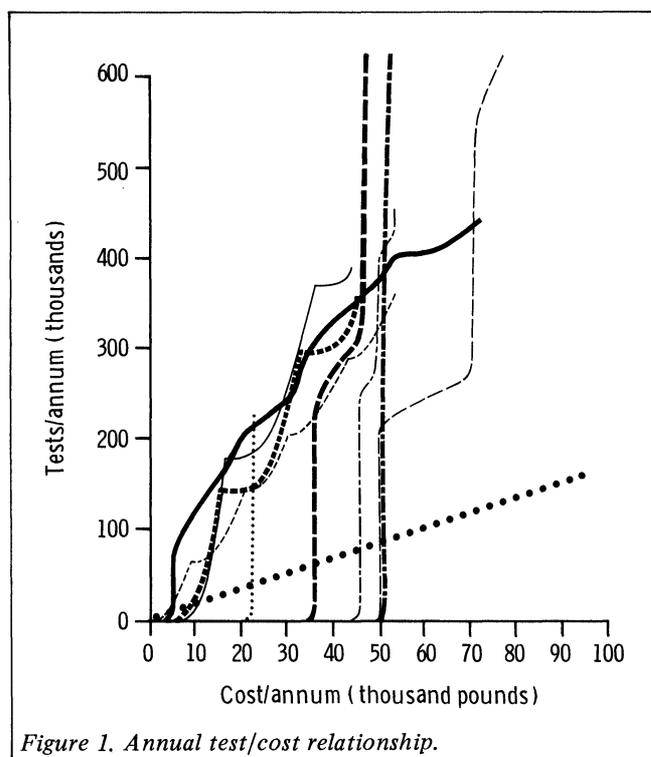
Figure 1. Annual test/cost relationship.

▬▬▬▬	Centrifichem 400	— — — —	Vickers M-300
••••••	DuPont ACA	▬·▬·▬·	Technicon SMAC

Table 6 Analyte associated costs of Union Carbide Centrifichem 400

	Method	Sample volume (μl)	Reagent volume (ml)	Reagent cost/1 (pence)	Cost/ test (pence)	Corrected reagent cost/test (pence)	Annual workload	Reagent annual cost (pounds)	Analyses (min/spec)	Total running time (h/annum)
Column	I	II	III	IV	V	VI	VII	VIII	IX	X
Derivation	see Table 2			see Table 2	$\frac{III}{1000}$ x IV	V + 16% V	see Table 1	$\frac{VI}{100}$ x VII		$\frac{(IX+20\%IX}{14) VII}$ $\frac{}{25) 60}$
Acid phosphatase										
Albumin	I	3	0.407	38.0	0.0155	0.0180	42684	7.68	0.133	511.9
Alkaline phosphatase	II	5	0.305	4770.0	1.4549	1.6877	28236	476.54	0.033	282.2
Blank										
Amylase										
Aspartate transaminase	I	40	0.305	4036.0	1.2310	1.4280	28452	406.29	0.033	284.3
Blank										
Bicarbonate										
Blank										
Bilirubin (total)	I	25	0.305	59.9	0.0183	0.0212	25404	5.39	0.133	304.7
Bilirubin (conjugated)	I	40	0.305	59.9	0.0183	0.0212	276	0.06	0.033	2.8
Blank	I	—	0.305	59.9	0.0183	0.0212	25404	5.39	0.033	253.9
Calcium	I	5	0.405	50.7	0.02053	0.0238	29580	9.04	0.033	295.6
Chloride										
Cholesterol	I	5	0.375	6632.0	2.487	2.8849	10848	312.96	0.500	209.7
Creatine kinase	I	15	0.385	2380.0	9.1669	10.6336	8736	928.95	0.033	116.2
Creatinine	I	40	0.405	17.8	0.0072	0.0084	11628	0.98	0.033	116.2
Blank										
γglutamyl transferase	I	25	0.305	6633.0	2.0231	2.3468	2604	61.11	0.033	26.0
Blank										
Glucose	I	5	0.305	108.5	0.0331	0.0384	21732	8.35	0.200	289.8
Iron	I	100	0.250	59.4	0.0149	0.0173	8064	1.40	0.333	129.0
Iron binding capacity	I	100	0.250	59.4	0.0149	0.0173	8064	1.40	0.333	129.0
Lactate dehydrogenase	I	10	0.300	3800.0	1.1400	1.3224	612	8.09	0.033	6.1
Blank										
Phosphate										
Potassium }										
Sodium }										
Total protein	I	10	0.405	25.2	0.0102	0.0118	42540	5.02	0.033	425.1
Blank										
Triglyceride	I	5	0.375	1192.0	0.4470	0.5183	2472	12.82	0.0333	39.5
Blank										
Urate	I	10	0.300	29.0	0.0087	0.0101	11928	1.21	0.167	151.2
Blank	I	10	0.300	135.5	0.0405	0.0470	11928	5.61	0.167	151.2
Urea	I	5	0.375	103.4	0.0388	0.450	53004	23.85	0.008	503.2

Columns VI to XIV refer only to batched analysis   Columns XV to XIX refer only to non-batched analysis

Technicon SMAC   £62,212.60   Albumin, alkaline phosphatase, aspartate transaminase, bicarbonate, total and conjugated bilirubin, calcium, chloride, cholesterol, creatine, kinase, creatinine, glucose, lactate dehydrogenase, phosphate, potassium, sodium, total protein, triglyceride, urate, urea)

Hycel-M   £53,700.14

Technicon SMAII   £49,178.57   (same as Vickers M-300)

These figures are not directly comparable for two reasons. The number of analytes determined is different; 15 with the M-300, 20 with the SMAC, 25 with the Hycel-M and 15 with the SMAII. The Hycel-M assays the complete workload model whereas the other three non-selective instruments cover only the profile workload defined by their capacity. The difference, therefore, between the performance of Hycel-M and the others is the total workload minus the respective profile workloads which is approximately 10,000 assays for sodium, potassium, bicarbonate and urea, plus the non-batched workload.

Systems using smaller instruments

Examples of systems capable of carrying out the batched and non-batched workload are shown below using different combinations of Kem-O-Mat, Abbott VP and Centrifichem. The cost of an AAII flame unit is included as none of these instruments is capable of sodium and potassium analysis.

AAII Flame Unit + 5 Kem-O-Mats
Flame Unit   £5,154.18
Kem-O-Mat   £57,320.40
                                  ⎯⎯⎯⎯⎯⎯
    Total/annum   £62,474.58

The analytes excluded are acid phosphatase, amylase, bicarbonate, γ–glutamyl transferase, iron and IBC.

AA11 Flame Unit + 3 VPs
Flame Unit   £5,154.18
VP Instruments   £43,878.70
                                  ⎯⎯⎯⎯⎯⎯
    Total/annum   £49,032.88

Acid phosphatase is the only analyte exluded.

AAII Flame Unit + 3 Centrifichems
Flame Unit   £5,154.18
Centrifichems   £46,932.03
                                  ⎯⎯⎯⎯⎯⎯
    Total/annum   £52,086.21

The analytes excluded are acid phosphatase, amylase, bicarbonate, chloride and phosphate.

AAII Flame Unit + Kem-O-Mat + 2 VPs
Flame Unit   £5,154.18
Kem-O-Mat   £9,825.22(Creatine, urea)
VPs   £33.408.70(rest of the analyses)
                                  ⎯⎯⎯⎯⎯⎯
    Total/annum   £48.388.10

Acid phosphatase is the only analyte excluded.

Table 6.continued

Electrical manpower cost/annum (pounds)	Specimen cost/ annum (pounds)	Laundry cost/ annum (pounds)	Total cost/ annum (pounds)	Corrected reagent cost/test (pence)	Annual workload	Annual cost reagent (pounds)	Analysis time (min/ spec)	Total running time (h/annum)	Electrical cost/ annum (pounds)	Specimen cost/ annum (pounds)	Laundry cost/ annum (pounds)	Total cost/ annum (pounds)
XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII
$3.31 \times X$	$\frac{1.5012}{100}$VII	$\frac{0.0932}{100}$VII	VIII+XI+XII +XIII	4V	see Table 1	$\frac{XV}{100}$×XVI	as IX	(5×VIII+ 10)$\frac{XVI}{60}$	$\frac{8.952}{100}$×XIX	$\frac{6.9}{100}$XVI	$\frac{2.33}{100}$XVI	XVII+XX+ XXI+XXII
1696.39	640.77	39.78	2382.62									
934.08	423.88	26.31	1860.81									
941.03	427.12	26.55	1800.99									
1008.58	381.36	23.71	1419.04	0.0732	240	0.18	0.133	42.7	3.82	16.56	5.92	26.48
9.27	4.14	0.23	13.70	0.0732	204	0.15	0.033	34.6	3.10	14.08	4.75	22.08
840.41	381.36	23.71	1250.87	0.0732	240	0.18	0.033	40.7	3.64	16.56	5.92	26.30
978.44	444.05	27.57	1457.10	0.0821	924	0.76	0.033	156.5	14.01	63.76	21.53	100.06
694.11	162.85	10.08	1180.00									
657.37	131.14	8.11	1725.57									
384.62	174.56	10.88	571.04	0.0288	36	0.01	0.033	6.1	0.55	2.48	0.84	3.88
86.06	39.09	2.44	188.70									
959.24	326.24	20.24	1314.07	0.1324	1404	1.86	0.200	237.9	21.30	96.88	32.71	152.75
427.00	121.06	7.48	556.94									
427.00	121.06	7.48	556.94									
20.26	9.19	0.55	38.09									
1407.08	638.61	39.70	2090.41									
130.75	37.11	2.29	182.97									
500.47	179.06	11.11	691.85									
500.47	179.06	11.11	692.25									
1665.59	795.70	49.47	2534.61	0.1552	2773	4.30	0.008	496.6	42.04	191.27	64.59	302.20

AAII Flame Unit + 2 Kem-O-Mats + 2 Centrifichems

Flame Unit	5,154.18
Kem-O-Mats	£18,876.84(Calcium, chloride, creatinine, phosphate, urea)
Centrifichems	£34,034.57(rest of the analyses)
Total/annum	£58,065.59

The analytes excluded are acid phosphatase, amylase and bicarbonate.

Conclusions

A method is proposed for assessing the cost of the annual workload and the capital depreciation of an instrument or instruments. The protocol has been standardised as much as possible so that it is easily applicable to all instruments currently used or to be used in clinical chemistry laboratories, individually or comparatively. This is one of the main advantages of RCAS over cost analyses carried out elsewhere as part of instrument evaluations on some instruments considered in the present study [3-5].

In the application of RCAS certain assumptions are made, particularly with respect to overheads which have been considered to be independent of the operation of the instruments. If at any time for any reason, one of these assumptions is considered invalid, suitable adjustments can be made to the cost analysis. A capital depreciation allowance is made for data processing equipment as an accessory to some instruments in order to level their performance with that of more advanced models which can be interfaced with a computer. It was not intended here, however, to include an analysis of computer costing. This, and the overheads referred to above are assumed to be independent of instrumentation and could be the subjects of separate RCAS programmes. A combination of all three would give a total costing similar to that of Coopers and Lybrand [1].

Ten types of instrument have been costed covering the range which is, or soon will be, available in the UK to the clinical chemist for the analysis of end point and/or rate of reaction. Combinations of these instruments have been costed for the execution of a defined workload with the general conclusion that the more recently introduced instrumentation is more economic, and that if the correct combination is used it makes little difference whether the system is based on a large multichannel analyser or a series of smaller discrete instruments. The costing of the newer instruments is based more on the theory than the practice of operation and therefore it is possible that the data used give a falsely low costing.

One of the most important aspects of instrumentation not considered by RCAS or other costing procedures is the quality of analysis. This cannot be evaluated mathematically but it can be assessed comparatively for different instruments and therefore provides a basis for justification of the cost of a particular chemical method or instrument.

The equipment and systems covered in this paper represent only a small part of the total number available but the study was laborious and time consuming. It is suggested that RCAS would operate most effectively through a computer program. It is also recommended that a costing file containing all the information concerning the cost of capital, reagents, disposable items, service and manpower should be kept and updated periodically to allow for price increases. A separate file could contain instrumentation details with the new information entered as it becomes available. A relative cost analysis could then be carried out at any time for a given workload using any specified combination of instruments. The compilation of such a program would make it easier

Table 7. Instrument cost analysis (pounds/annum)

Instrument	Vickers M–300	Technicon SMAC	Hycel M	Technicon SMA II		Technicon AA II		LKB 8600
Instrument associated costs	50,736.60	50,955.05	45,671.46	see below		see below (c)		(d) 2,150.00
Type of workload	Profile	Profile	Total (a)	Profile	(b) Non batched	Batched	Non batched	Batched
Analyte	Analyte associated costs (pounds)							
Acid phosphatase			9.43	553.89		82.55		111.01
Albumin	125.89	7.06	13.96	50.14		2,202.20		
Alkaline phosphatase	80.17	707.39	2,202.89	7,087.53		6,171.95		4,140.70
Blank	69.86							
Amylase			0.28					
Aspartate transaminase	9,550.39	256.52	999.96	3,849.37		4,069.55		3,910.48
Blank	9,550.39							
Bicarbonate	5,894.44	0.44	449.58	4.21	8.30	588.59	207.95	
Blank	96.05							
Bilirubin (total)	240.10	9.63	15.10	58.58	115.47	1,408.35	27.29	
Bilirubin (conjugated)	240.10	9.63	0.86	58.58	115.47	234.19	23.20	
Blank	240.10	9.63	15.10	58.58	115.47	1.408.35	27.29	
Calcium	169.30	14.26	13,45	43.08	84.92	1,593.72	100.15	
Chloride	38.80	1.30	0.25	9.93		275.66		
Cholesterol	594.22	93.34	1,242.01	133.69		747.05		2,012.84
Creatine kinase		2,242.23	1,955.85	10,148.80		3,193.13		4,625.94
Creatine	58.98	1.65	2.32	4.37	8.62	744.33	3.43	
Blank	2.65		0.10					
Gamma glutamyl transferase	15,695.66		203.18					836.16
Blank	15,695.66							
Glucose	410.78	33.64	41.33	118.10	232.81	1.267.25	188.15	
Iron			4.54	45.78		590.83		
Iron binding capacity			4.54			590.83		
Lactate dehydrogenase	12,588.72	735.53	52.84	6,655.89		543.88		324.01
Blank	81.87			44.59		157.10		
Phosphate	181.91	1.59	13.41	47.53		1,525.63		
Potassium }	4.06	89.03	1.12	1.27	2.51	2,727.78	307.51	
Sodium }		71.03						
Total protein	83.48	4.68	9.24	53.49		2,218.37		
Blank		3.85		43.71		2,207.17		
Triglyceride		3,880.82	660.17	14,688.45		2,049.05		1,036.93
Blank		2,994.51						
Urate	93.33	77.81	4.34	316.02		858.03		
Blank	436.07		20.30					
Urea	342.55	11.98	92.53	37.67	74.26	2,680.07	295.62	

to deal with the problem of cost changes due to inflation. Meanwhile it can be said that from the beginning of the last quarter of 1978 to the end of the first quarter of 1980, manpower costs have been increased by 25.2% based on the change in the mean salary of the MLSO and other costs by 24.5% based on the change in the retail price index.

REFERENCES
[1] Coopers and Lybrand. Procedure for determining test costs in pathology laboratories, 1975, Department of Health and Social Security.
[2] DHSS Pathology Statistics Annual Report Form (SBH6).
[3] Clarke, A. A. and Dill, C. M., Final report on the SMAC costs in the Biochemistry Department of the Royal Victoria Hospital, Belfast, 1976, Department of Health and Social Security.
[4] Robinson, R. and Rock, P. Evaluation of DuPont automatic clinical analyser at George Eliot Hospital, Nuneaton, 1979, Department of Health and Social Security.
[5] Clark, A., Jones, P., Davies, A., Saunders, R. and Noon, D. A cost evaluation exercise of the centrifichem parallel fast analyser, 1977, Welsh Office.

Key to Table 7.

(a) The Hycel—M is designed to be maintained in a standby mode and therefore batched and non-batched analyses may be costed together.

(b) The instrument associated costs for SMAII are £16,767.79 excluding pump tubes (£64.20 per channel) and capital depreciation and maintenance. These costs are dependent upon the number of channels and whether a flame unit is included. Figures are quoted below for 6 to 16 channels including flame unit.

6 channels	£9,990.00
7 channels	£10,836.00
8 channels	£11,470.00
9 channels	£12,633.00
10 channels	£14,324.00
11 channels	£15,487.00
12 channels	£16,544.00
13 channels	£17,390.00
14 channels	£18,553.00
15 channels	£19,187.00
16 channels	£19,610.00

The instrument associated costs cover profile and non-batched work as it is assumed that an instrument used for non-batched analysis would also be used for profiling. If the non-batched analysis is to be included however, there is an additional £1,546.00 to cover services, commercial sera and disposables costs.

(c) Instrument associated costs have been calculated for flame units and dual channel systems only, these are £2,118.89 and £1,637.35 per channel respectively.

(d) The cost of an LKB 2082—018 Kinetic Data Processor has been included under the capital.

(e) At the time this data was collated no information was available on the manufacturers maintenance contract. This has been assumed to be 5% of capital cost. Also, an allowance has been made in the capital cost to cover a micro-processor and interfacing equipment which were not currently available.

(f) This costing is based on the "fee per test" method and therefore there is no instrument associated cost.

Coulter KEM–O–MAT		Abbott VP		Centrifichem 400		Du Pont ACA	
(e) 2,730.00		6,649.43		7,928.57		None (f)	
Batched	Non Batched	Batched	Non Batched	Batched	Non Batched	Batched	Non Batched
						897.92	
4.509.18		2,319.67		2,382.62		27,308.25	
3,638.32		2,144.10		1,860.81		18,247.29	
		127.08	16.27			1,886.15	359.40
3,526.65		2,116.90		1,800.99		18,409.77	
		551.40	336.03			5,663.61	2,939.63
2,685.02	21.12	1,381.51	25.25	1,419.04	26.48	16,323.05	554.27
29.18	17.93	14.90	21.45	13.70	22.08	658.79	471.12
2,685.02	21.12			1,250.87	26.30		
3,127.38	81.31	1,608.55	97.14	1,457.10	100.06	19,079.17	1,487.80
146.80		80.78				1,366.35	
1,158.67		894.55		1,180.00		7,307.13	
1,988.43		1,186.19		1,725.57		5,996.32	
1,226.54	3.13	631.20	3.75	571.04	3.88	7,813.24	83.71
		204.81		188.70		2,149.22	
2,316.16	127.49	1,268.82	149.11	1,314.07	152.75	14,146.85	2,040.67
		469.70		556.94		5,602.93	
		469.70		556.94		5,602.93	
75.45		42.82		38.09		892.38	
2,966.13		1,141.08				18,120.03	
4,488.53		2,473.25		2,090.41		27,230.29	
440.11		225.40		182.97		2,046.66	
1,258.99		743.38		691.85		7,989.21	
1,266.19				696.25			
5,618.37	247.18	2,891.60	294.01	2,534.61	302.20	33,791.85	3,617.93