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AUTHOR	Simmonds, W. H.; And Others
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ABSTRACT

The aim of this study was to develop methods, based upon computer simulation, of designing information systems and illustrate the use of these methods by application to an information service. The method developed is based upon Monte Carlo and discrete event simulation techniques and is described in an earlier report -- Sira report R412 Organizing and Planning Complete Production and Service Oriented Systems. This report discribes the programme of analysis and experimentation carried out using the model and the results obtained. The report is in seven sections. Sections 3 and 4 summarize the structure of the information service studied, the Sira Industrial Communications Group, and the method of modelling. Section 5 describes the data collected in order to quantify the model and discusses difficulties encountered. The programme of analysis and experimentation is detailed in Section 6 and the final section interprets and presents the results obtained. (Author/NH)

Sira Report

COMPUTER SIMULATION AS AN AID FOR MANAGEMENT OF AN INFORMATION SYSTEM

by W H Simmonds, BSc ARCS AFIMA
J M Myers, A I Inf Sc
V Maguire, BSc Grad IMA

R454 April 1970 C

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1 INTRODUCTION

In all production systems problems arise because demand for products fluctuates and a fast response must be provided to remain competitive. If the products are standard and the demand for any single product is reasonably predictable the problem can be overcome by holding a stock of these products and, therefore, providing immediate supply from stock. If, however, the product variants are so numerous that the demand for any one item is very small and highly unpredictable the solution of holding stocks becomes completely uneconomic, and perhaps impossible.

An extreme case of this latter situation is met in information services where the product, which may for example be the answer to an enquiry, is an unknown quantity until the order (ie enquiry) has been received. In these cases the cost of providing a fast response is that of accepting under-utilisation of production resources rather than that of typing up capital in stocks. A further complication in these situations is that each order may initiate a different course of action and consequently it often proves impractical to lay down set procedures for production; each order requires individual attention and for economy the control of the work must be largely delegated to the persons actually performing the work.

A study of service-oriented production systems, of the above nature, has been carried out at Sira. The aim of this study was to develop methods, based upon computer simulation, of designing such systems and illustrate the use of these methods by application to an information service.

The method developed is based upon Monte Carlo and discrete event simulation techniques and is described in an earlier report – Sira report R412 Organizing and Planning Complete Production and Service Oriented Systems. This report describes the programme of analysis and experimentation carried out using the model and the results obtained.

The report is in seven sections. Sections 3 and 4 summarize the structure of the information service studied, the Sira Industrial Communications Group, and the method of modelling, both of which are treated more fully in the earlier report R412 mentioned above. Section 5 describes the data collected in order to quantify the model and discusses difficulties encountered. The programme of analysis and experimentation is detailed in Section 6 and the final section interprets and presents the results obtained.

2 CONCLUSIONS AND RECOMMENDATIONS

A difficulty frequently encountered in Operational Research studies is that unless the study is compressed into a sufficiently short space of time the resultant recommendations will relate to a situation which has passed. Often however, it is found that the recommendations have been implemented before the study is completed because these are foreseen as a result of the early probing stages of the study.

This study was carried out by a small team, only one person was engaged in the study full time, and took 20 months to complete. In this period changes were made in the services operated by the Industrial Communications Group for reasons in no way connected with the study; although the way in which certain changes were effected was influenced by the study.

The project is presented in this report as a complete case study so as to illustrate clearly the steps taken in identifying the operation of the system, the methods of analysing its performance and the quantitative recommendations that can be obtained. However the above comments must be borne in mind whilst reading this case study. Having now developed the techniques and constructed general purpose computer simulation programs other similar studies can be executed more rapidly.

The computer programs have in fact already been used to perform a quick simulation of a production system as a part of another study. Without these programs this would not have been possible because the time taken to carry out the analysis would have been unacceptable.

3 STRUCTURE OF THE INDUSTRIAL COMMUNICATIONS SYSTEM

For convenience this report refers to the system studied as 'the industrial communications' system. This title does not indicate the full scope of the work carried out by the system, which includes enquiry services, library services, publications, organisation of meetings and conferences and special information processing contracts. These functions are listed with subclassifications in table 1.

In order to perform these functions various grades of staff are required. These staff can be classified broadly as senior technical, junior technical, clerical, and secretarial. With the possible exception of organising meetings and conferences it is obviously desirable that the services operated should overlap, both because the information systems should be common so as to avoid duplications and because staff should be shared so as to maintain a degree of integration in similar information processing activities. Beyond this necessary overlapping further sharing of staff between services is thought desirable for purposes of economy and security against unforeseen circumstances such as absence of staff due to illness and extreme peaks in demand for a service.

Each call on a service, or initiation of a job, sets into motion a sequence of activities, although this sequence is not generally known at the time of initiation. An enquiry,

for example, may be dealt with by reference to recorded information or, if the answer is not found in this way, may necessitate a much more lengthy procedure involving consultation of specialist staff elsewhere in Sira and in other organisations.

It is possible, after the event, to classify each job performed according to the sequence of activities involved.

In the absence of complete prior knowledge of how a particular job will be dealt with, formal work control is severely limited. A large degree of reliance has to be placed upon staff using initiative, behaving in a conscientious manner and deciding the relative priorities of different jobs (both between jobs within a service and between jobs in different services) since these are dynamic and depend upon stages of job completion relative to target completion times. Prior scheduling on an individual job basis is impractical for all but the major projects.

4 METHOD OF MODELLING THE SYSTEM

A model was required which would enable the behaviour of the system to be studied in detail at the operational level. System characteristics of importance at this level are utilisation of resources and service response. For these reasons a discrete event model was regarded most appropriate.

In this form of model the system operation is described in terms of activities, each of which can take place following a preceding discrete event and which, having taken place, gives rise to a succeeding discrete event.

Each activity must be described by its duration and the resource required.

Any total job that can be performed by the system must be described in terms of the sequence, or network, of activities which, when performed, will complete the job.

In addition, the resources, ie staff, that are available in the system must be described in terms of their cost.

The behaviour of the system can only be studied by presenting it with a work load. This work load must consist of a mix of jobs arising in accordance with the statistical pattern of real life, or perhaps some modified pattern which is expected in future or needs to be explored for other reasons.

5 COLLECTION OF DATA TO QUANTIFY THE MODEL

A frequent worry in attempting to analyse the behaviour of real life systems is that quantities depend upon many different things, particularly where one or more of these things is a human characteristic. Management do, however, have to decide such quantities as numbers of staff required to operate a particular service. Judgment based upon measurement of variations and means of quantities, such as times taken in performing activities, are likely to be better than judgment based upon total system feedback, such as reported complaints of overloading (underloading may not be reported) and subjective comparisons between distribution of capacity and work load, based upon impressions which can very easily have been distorted or camouflaged.

If quantities are unpredictable, management should endeavour to determine the degree of unpredictability and plan to balance the degree of security against the costs of security.

For these reasons the emphasis in collecting data was on measuring, or assessing the likely span of quantities rather than just a mean or most likely quantity.

The data required can be grouped under three headings

Demands
Activities
Resources

5.1 Demands

The various demands upon the services provided by the system can, as previously mentioned, be classified according to the sequence of activities initiated. Each such activity sequence is termed a path. The total number of paths is very large and for the purpose of analysis they are grouped into categories.

CATEGORIES OF DEMAND

Category	Description
1	Simple enquiries
2	Commercial enquiries
3	Technical enquiries
4	Enquiry service report
5	Processing serials
6	Production of abstracts
7	Processing leaflets and photocopy service
8	Book purchasing
9	Interlibrary loans
10	Library enquiries
11	Production of abstracts index
12	Incoming and outgoing post
13	Special contract information processing
14	Other work

For each path the pattern of demand arrivals has to be determined.

5.1.1 Individual demands

Some demands arrive individually and randomly. Telephone enquiries, for example, are received individually and at any time during the working day, although in this particular case they are found to be more frequent at certain times of the day. Records of telephone enquiries over a period of several weeks were used to find the distribution of the numbers received in each day. Staff dealing with these enquiries were consulted to estimate the pattern of arrivals within a day.

5.1.2 Batched demands

Some kinds of work—for example serials being processed through the library on routine circulation—arrive in batches at fairly well defined times. In these cases the distribution of batch sizes has to be determined.

If the batch of demands is never separated but is processed throughout as a batch, there is no need to separate the individual demands. Instead the variation in batch size is taken into account by determining the duration of the various activities, not in terms of individual items, but in terms of complete batches. It should be noted that any attempt to split these batches into individual items leads to extreme complications since the only meaningful data that can be collected are, in most cases, distributions of activity durations per batch.

5.2 Paths

It is characteristic of information and library systems that the work comprises a large number of jobs which require a relatively small number of activities to complete. Many of the activities are similar for a large number of jobs. This contrasts with project work in which critical path techniques are helpful to schedule the very large number of dissimilar activities involved in one job.

Each demand entering the system can be 'exploded' into the activities which have to be undertaken to complete it. For each category of demand there may be many different paths, ie sequences of activities, which occur in practice. 'Quick enquiries', for example, may be answered from personal knowledge, from indexes, from reference books or by contacting a specialist who knows the answer. The sequence of activities will also vary according to how the demand arrives—by telephone, by letter, or by someone calling in at the library.

All possible paths have to be identified and the data requirement described in section 5.1 above relates to individual paths.

5.3 Activities

The distinguishing features of each activitity are the time it takes and the resource required. Although two activities may be physically dissimilar, if they can be performed by exactly the same set of resources and the spread of times taken are similar, they can be regarded as the same activity. If on the other hand two physically identical activities differ by virtue of the staff allowed to perform them, or their duration, they must be regarded as different activities.

Deciding the staff that can, and are permitted to perform each activity does not generally pose severe problems. The duration of an activity, however, will vary according to the person doing it and the job of which it is a part. In some cases it may be possible to state, with some degree of realism, the relative speeds of different staff when performing a particular activity. Provision for such estimates is made in the computer programmes, but has not yet been used. Times for all activities are required in terms of three estimates—minimum time, expected time, maximum time. Estimates were obtained in various ways. For several activities staff were asked to provide their own estimates. In some

cases staff were timed over several activities and in other cases a member of the investigating team, with past experience in these activities, joined the staff for a period of several days and timed himself. For those activities on which all three methods were used, good agreement was found except that estimates provided by staff varied from person to person, their combined estimates being encompassed by those obtained using the other methods. To some extent this difference is thought to reflect the selection of difficult, long jobs by some staff and easy, short jobs by other staff.

5.3.1 Activity classification

Activities fall into different classes of 'type of work', Analysis of system behaviour on an individual activitity basis would be of little value where the number of activities is very large. A more useful analysis is based upon type of work.

All activities were classified by work type. It was found however that staff were not confined to activities in a particular work type class. In may cases considerable flexibility was allowed. The activity categories involved in each demand category are shown in table 2.

5.4 Resources

Sira's Industrial Communications Group is labour intensive and all the resources described are in fact staff resources. Activities have, above in section 5.3, been defined in terms of the resources suitable. At this stage it is only necessary to state the cost of each resource.

5.5 Difficulties encountered

Acquiring the data described above is a laborious task if the system is complex. Where existing records are insufficient to provide the necessary information, special recording systems may be required and must be operated over lengthy periods of time. Immediately the problem of system evolution becomes apparent. The data base obtained at any time becomes out of date before it is sufficiently complete to be used.

The period of time elapsing whilst data is collected can be further protracted if too much attention is given to detail. A compromise between economy of time and accuracy of data must be accepted. Data which are out of date is in any case not accurate.

A period of many months was required in collecting the information for this study. The process of learning how much detail should be used was severely hindered by changes in the system during the study and the analysis suffers from some shifting in the data base.

Programmes were developed in parallel with data collection. This caused yet further protraction of the time span.

6 PROGRAMME OF ANALYSIS AND EXPERIMENTS

The major part of the work in the Industrial Communications Group is concerned with operating the enquiry services. This area of work was selected as the starting point for data collection, analysis and experimentation Information collected in this area was also used for developing the methods of data collection, for testing the computer programmes and checking the methods of analysis. Several changes took place in the Industrial Communications Group during and immediately following this initial work. Consequently the results of the initial analysis and experimentation must be regarded as largely separate from the remainder of the project and care must be exercised in combining or comparing results.

In this report a full description of the analysis and experimentation work using the final data base will be given. In the case of the work carried out using earlier (transitional) data bases, presentation in this report will be largely confined to the results obtained and conclusions drawn.

The objectives of the analysis and experiments using the final data base were to examine

- Balance between the rates of incoming work and the resources available
- Consequences, in terms of operating costs and system response, of changing the flexibility of the system in terms of sharing staff between different jobs
- Consequences, in terms of operating costs and system response, of changing the degree of adherence to priorities in selection between different jobs by staff
- Bottlenecks in the current system and suitable ways of relieving them

6.1 Comparison of work load with work capacity

The rate of incoming work was analysed in relation to the capacity available by considering a six week period. The demand simulation programme was used to generate a typical mix of demands over the six week period and these were then broken down into daily quantities of incoming work, by work category, using the work load analysis programme.

The categories of work considered in this analysis were as follows.

CATEGORY	AREA OF WORK	GRADE OF WORK
1	Enquiry services	Senior technical
2	Enquiry services	Junior technical
3	Enquiry services	Clerical
4	Enquiry services	Secretarial and typing
5	Library and documentation	Senior technical
6	Library and documentation	Junior technical
7	Library and documentation	Clerical
8	Library and documentation	Secretarial and typing
9	Group services	Secretarial and typing
10	Special contract service	Senior technical
11	Special contract service	Junior technical
12	Special contract service	Secretarial and typing

Capacity available to meet this work load is not easily defined. A total of 19 staff is available for work in the areas considered, but, with the exception of four of these staff, they are suitable for work in more than one area.

All of these staff are, in addition, called upon by other demands which are too diverse to be described in other than an aggregate form. The extent of these other demands was found by examination of their time sheets over a four week period. The remaining available time is found to be as below, expressed in average hours per week.

GRADE	AVAILABLE TIME h	TOTALS h
1 Senior technical	6.9	
2 Senior technical	25.7	
3 Senior technical	11.6	
4 Senior technical	33.0	
5 Senior technical	24.6	
6 Senior technical	30.0	
7 Senior technical	26.1	157.9
8 Junior technical	32.8	
9 Junior technical	34.4	
10 Junior technical	33.6	
11 Junior technical	14.5	
12 Junior technical	30.2	
13 Junior technical	34.1	179.6
14 Clerical	34.6	
15 Clerical	30.9	65.5
16 Secretarial and typing	34.2	
17 Secretarial and typing	35.2	
18 Secretarial and typing	35.8	
19 Secretarial and typing	34.0	139.2
	TOTAL	542.2

Of these staff, 11, 12, 13 and 14 should be in view of their capabilities be employed entirely within the library and publications area. Other staff should also, for reasons such as suitability of experience and training, be confined to particular areas of work. In consequence, the availability of effort in each of the 12 areas of work is as follows

Senior technical

76.1 hours per week shared between enquiry services and library/publications

81.8 hours per week shared between enquiry services library/publications and special contracts

Junior technical

78.8 hours per week exclusive to library/publications

32.8 hours per week shared between library/publications and special contracts

68.0 hours per week shared between enquiry services,library/publications and special contracts

Clerical

34.6 hours per week exclusive to library/publications

30.9 hours per week shared between enquiry service and library/publications

Secretarial typing

34.0 hours per week shared between library/publications and special contract

34.2 hours per week shared between enquiry services,library/publications and group services

71.0 hours per week shared between enquiry services,library/publications, group services and special contracts

The average quantiities of work entering the system in a week are shown below together with the resource capabilities available. In this table work can be transported only via the circles.

WORK		RESOURCE AVAILABLE h (TOTAL 542.2)									
CAT.	QUANTITY h	76.1	81.8	78.8	32.8	68.0	34.6	30.9	34.0	34.2	71.0
1	67.7	o	o								
2	60.6					o					
3	34.6							o			
4	33.4								o	o	o
5	68.2	o	o								
6	34.9			o	o	o					
7	113.0						o	o			
8	19.7									o	o
9	4.8									o	o
10	12.1		o								
11	24.5				o						
12	2.5								o		o
TOTAL	475.0										

The total incoming work each week for each staff grade is shown in figures 1 to 4.

Several observations can be made

1 The total resource availability is about 10% greater than the long-term average rate of arrival of work. The work arriving in any one week can be greater than the capacity available. The daily arrivals of work are considerably more erratic but a comparison on this basis is of little meaning because work arriving in a particular day need not, and in many cases cannot, be performed in that same day.

2 The total senior technical effort available exceeds the average weekly incoming work rate by only about 6%. The weekly work load entering the system can exceed the effort available.

3 The total junior technical effort available exceeds the average rate of incoming work by more than 50% and the probability of the incoming work in any one week exceeding capacity is negligible. In examining the distribution of this capacity between the different functions we find, however, that the excess of capacity lies almost entirely in the library/publications area and in this connection the observations under note 4 below should be considered.

4 The total clerical effort is less than the average rate of incoming work. The effort available is insufficient in both the enquiry service area and the library/publications area. This deficiency must, in practice, be countered by junior technical staff, who as seen in note 3 above are underloaded with technical work, carrying out clerical work.

5 The secretarial capacity available is over 100% greater than the work load. The spare capacity is, again, diverted to certain clerical activities. If the clerical and secretarial/typing figures are combined we find total incoming work rate just exceeds total capacity and the conclusion that clerical work is consuming technical resources thus still holds.

On examining the real situation it is found that, whilst clerical bottlenecks would occur if staff performed only the preferred and most appropriate activities, problems are avoided because junior technical staff and secretarial/typing staff do in fact perform a number of the clerical activities.

6.2 Simulation experiments

The simple analysis described above provides no insight to the dynamic behaviour of the system. Demands arriving into the system in a particular day initiate a sequence of activities, some of which can only be performed much later. How much later depends not only upon the number of activities in the job and their durations, but also upon the amount of time for which the job waits between activities because the appropriate staff are occupied in other work.

This dynamic behaviour is examined by simulating, in a discrete event fashion, the operation of the system.

Two characteristics of the real system which must be defined in order to simulate its operation are

- the system flexibility
- the degree of work control

6.2.1 System flexibility

Staff are, in practice, always capable of performing activities outside the range for which they were employed. Determining the true level of flexibility in a real system is not easy. Whilst staff confine themselves to the intended area most of the time they will, particularly at the intermediate levels, carry out other activities so as for example, to avoid waiting for the proper person to get round to doing it.

If the balance of staff is properly planned the proportion of this transfer of work between staff should be controllable. Some transfer will probably be desirable because in this way system response can be increased and a higher overall utilisation of resources obtained. However, if the level of transfer is too high then the costs per job increase and the availability of free effort at the more valuable levels diminishes.

The difficult problem of determining the real extent of this flexibility existing at present was avoided by instead defining two limits between which the actual level is confidently expected to lie.

6.2.2 Degree of work control

When a particular member of staff finishes one activity there can be several jobs awaiting. A decision has to be made in selecting one of these jobs. In practice this selection depends upon an extremely large number of factors which cannot be defined with any confidence.

We can, however, again overcome the problem by stating upper and lower bounds on the decision procedure.

6.2.3 The three experiments

Three simulations were performed, each having a duration of a few weeks. It is confidently expected that these three simulations emcompass the real life system, although no one of them corresponds exactly.

In the first simulation staff were only allowed to work in the more appropriate activity areas and the selection of jobs was based upon the following rules. For each job entering the system a minimum completion time is calculated (ie the critical path time). As the job progresses by activities being performed, the times of the completed activities are deducted from the critical path time. Target job durations are set, by management, and are used to calculate a target completion time for each job entering the system adding the target job duration to the time of arrival of the job. The jobs being considered for allocation to a person, when he becomes free, are divided into two groups: those which are well ahead of time and those which are overdue or becoming overdue. The jobs in each of these groups are then arranged in order of relative priority

and allocated to staff in this order. The jobs overdue or becoming overdue are allocated first and in cases where more than one member of staff can perform the job (and is available at the appropriate time) the person capable of performing it most quickly is selected, regardless of cost. The jobs ahead of time are allocated by choosing the lowest grade (least expensive) staff available and appropriate, regardless of speed.

In the second simulation the method of allocating jobs to staff was altered. Jobs in this case were allocated on a first-come first-served basis and where, more than one person was both appropriate and available, the selection was random.

In the third simulation staff were allowed to work in rather wider activity areas but jobs were assumed to be controlled by the method adopted in the first simulation.

The three systems are summarized below

Flexibility of system	Degree of control	
	Loose	Close
Flexible	–	Simulation C
Constrained	Simulation B	Simulation A

7 INTERPRETATION OF RESULTS

The three simulations can be used to examine the performance of the real life system and identify its weaknesses by roughly averaging the three sets of results. By comparing the results of the different simulations the effects of system changes can be estimated.

7.1 Average system performance

In examining the average behaviour of the simulated system it is important to compare this, wherever possible, with the observed performance of the real system in order to verify the model. In nearly all cases only a qualitative verification has been found possible by virtue of lack of quantitative measurements of overall performance in the real system. To make these measurements would, except in relatively few instances, be prohibitively expensive. The system behaviour found by the simulations does correspond well with observations of the real system and there are no obvious instances of contradiction.

7.1.1 System bottlenecks

The simulations present analyses of the queue lengths for each category of work. The proportion of time for which queues exceed a given level

is shown for each category of activity in figure 5. Examining these it is found that a severe bottleneck occurs in the clerical area, this being most acute in the case of library/publications work

A slight bottleneck also occurs in senior technical work in the enquiry service area.

7.1.2 System response

In relation to the targets set, the system response is inadequate in the case of enquiries, processing of leaflets and photocopy services. This is shown in figure 7.

7.1.3 Resource utilisation

Figure 8 shows the proportion of available time that is utilised. The senior technical staff are well utilised. Those staff available for work in dealing with technical enquiries, preparation of abstracts and scanning technical literature are somewhat strained.

Utilisation of staff at the junior technical level is poor, particularly in the enquiry service area.

Utilisation of clerical staff is also poor, again particularly in the enquiry service area.

Secretarial and typing staff are very much underutilised.

It is important to note in relation to the above observations that low staff utilisation is not necessarily bad and can be essential for overall system optimisation. It is less costly for a typist to wait because of a bottleneck at the senior technical level than it is for a senior technical officer to wait because of a secretarial bottleneck.

The above observations appear to contradict the findings of the work load analysis in which it was concluded that clerical resources are overloaded. There is in fact no contradiction, the reason being twofold. Firstly, in all three simulations some latitude is given to staff enabling them to work outside their most appropriate area if a sufficient need arises. This latitude has the effect of down-grading staff whenever the system is under pressure. Secondly, work flows through the system predominantly from high level to low level. As a consequence a slight bottleneck at the senior technical level reduces the rate of flow of work into the clerical area.

Further examination of the simulation results shows evidence of both these happening.

7.2 Consequences of constraining the system

The system can be constrained by narrowing the range of activities each member of staff is allowed to perform. This form of constraint can be applied in two ways—between different services, and between different grades of work within a service.

The final programme of simulation experiments examines only the combined effects of both, and conclusions relating to each have been found difficult to obtain. However, earlier simulations of the enquiry service in solation showed that small changes in system flexibility resulted in significant improvements in response, at the expense of gross downgrading of staff. It was found, for one class of enquiries that whilst the average time lapse between enquiry receipt and answer despatch was reduced by about 40% the cost of the time of the staff dealing with these enquiries was more than doubled

7.2.1 System bottlenecks (see figure 5)

Narrowing the work range of staff, in the system under study, results in delays being reduced in senior technical enquiry work, but causes severe difficulties in handling the clerical work in both the enquiry and the library/documentation area.

Very little difference is effected in the flow of work in other areas.

7.2.2 System response (see figures 6 and 7)

Constraining the system results in an overall improvement in response. Jobs relying heavily on technical staff show significant improvement but the response in other areas deteriorates. For example, the preparation of statistical reports on the enquiry services suffers a tenfold increase in delay.

7.2.3 Costs of operating (see figure 10)

The average direct cost per demand is significantly reduced in the case of jobs with a high content of the lower grade labour but increased in the case of jobs with a high content of senior technical work.

7.2.4 Resource utilisation (see figure 8)

Constraining the system results in an overall reduction in the utilisation of staff at all levels. This is most marked, however, at the lower levels.

7.3 Conseqeunces of increasing work control

The various services operated by the system can be attributed different relative importance. At times when demand peaks and capacity cannot be correspondingly increased the more important services should assume priority. Various measures could be used to direct effort towards work of high priority. This would involve an additional cost in more detailed recording of job progress and work supervision.

7.3.1 System bottlenecks (see figure 5)

Increased observance of priorities moves bottlenecks away from the enquiry service (regarded as a high priority service) into the library/ documentation area (regarded as lower priority).

The balance between work load and capacity is sufficiently fine in the clerical areas that observance of priorities can in this way cause complete breakdown in the library and documentation services.

7.3.2 System response (see figures 6 and 7)

Average delays between receipt and completion of enquiries are reduced, for one class of enquiry by as much as 75%. Lower priority work, in the library/documentation area, on the other hand, suffers considerably increased delay. Some jobs would appear to risk never being completed.

7.3.3 Costs of operating (see figure 10)

The average direct cost of dealing with a job is generally incr in the enquiry services but decreased in the library/documentation area. In the case of technical enquiries an increase of nearly 20% results. Increased work control results in the most economic staff being used for jobs well ahead of schedule. This tends to balance the increased cost of using more expensive staff when jobs become urgent, except where the balance between work and capacity (or the target response time) is such that few jobs are ever well ahead of schedule.

7.3.4 Resource utilisation (see figures 8 and 9)

Increased observance of priorities results in greater pressure on the higher grade staff and poor utilisation of the lower grades of staff. Overall utilisation is significantly reduced.

7.4 Improving the system

The three simulations show the consequence of changes in flexibility of staff and degree of job control. In order to recommend changes which will improve the real life system it is necessary to define the objectives of this system.

These objectives can be listed individually but cannot easily be combined into one overall objective function. Listed individually they are to

- Maximise staff utilisation (ie throughput of work)
- Minimise the proportion of overdue jobs
- Minimise the direct costs of each service

7.4.1 Maximise staff utilisation

This is a real objective because demand levels are rising and the ability to delay staff recruitment results in economy. Staff utilisation is increased by making the system more flexible, as shown in figure 8. This however, also results in downgrading of staff, as can be seen (figure 10) from the slight overall increase in the direct costs per hour of operating the services. In some areas (eg technical enquiries) there is an upgrading effect which may be indicative of deterioration in the quality of the service. A further consequence is a fairly severe increase in the proportion of jobs which become overdue in spite of the fact that the average response time is not on the whole increased.

7.4.2 Minimise the proportion of overdue jobs

The overall proportion of overdue jobs is significantly reduced by introducing more strict job control, as can be seen in figure 7. This

however, also results in a lower overall rate of work flow. Close examination of the simulation results reveals that lower priority services in fact breakdown completely as a consequence of strict observance of relative priorities between the services in a system which is out of balance.

7.4.3 Minimise direct costs

Whilst it could be argued that no benefit is obtained by minimising the direct costs of operating the services, because the staff are employed anyway, there is in fact a benefit in biasing spare capacity towards the higher staff grades because the spare capacity is in practice utilised in developing the services of the system. It is found that making the system more flexible results in higher utilisation of the lower staff grades and lower utilisation of higher staff grades. Introducing more strict job control has the reverse effect, largely because the higher priority services tend to have a greater high grade work content.

7.4.4 Overall objective

In the short term the objective must be to maintain an adequate flow of work and complete as many jobs as possible without any being excessively overdue.

Figure 11 shows the results of the three simulations, relating the proportion of jobs completed on time to the utilisation of resources. Also indicated in this figure is the level of staff utilisation which must be exceeded in order to keep pace with the incoming work.

It is clear that in the case of systems A and B a steady state has not been reached in the simulations. As the simulations proceed the proportion of jobs overdue will continue to increase in the case of system B. In system A the proportion of jobs overdue appears to be settling, but only because the use of a job priority control is filtering out the high priority jobs and restricting the flow of low priority work.

It is evident that extreme staff flexibility is essential in the existing system. It is clear however, that this is largely a consequence of the poor balance between capacities to perform the different grades of work.

In the existing system attempts to introduce closer observance of priorities are extremely dangerous. Lower priority work will be neglected to the extent that some jobs are never performed.

The long-term objective must, for these reasons be to correct the balance of staff so as to achieve the necessary level of staff utilisation but at the same time allow priorities to be instructed without causing permanent breakdown of lower priority services.

Approved by Head of Industrial Communications Group
J M Myers, A I Inf Sc

For further information please contact:
Sira South Hill Chislehurst Kent BR7 5EH Telephone 01–467 2636 Telex 896649

TABLE 1

Demands

Category	Description	Target response	Relative priority
	Enquiries		
1	simple	½ h	high
2	commercial	1 h	high
3	technical	2 days	high
	scanning and indexing	1 day	high
4	statistical report	1 week	low
	Journals		
5	scanning	1 day	med
	obtaining commercial literature	1 day	low
6	abstracting	6 days	low
	displaying and circulation	3 days	low
	collection and distribution	3 h	low
	Leaflets		
7	scanning	3 h	low
	photocopy requests	1 day	med
	Books		
8	purchasing	20 days	low
	collection and distribution	1 h	low
	Library		
9	interlibrary loans	1 week	low
	chasing overdues on loan	2 days	low
10	enquiries	½ day	med
	Publications		
11	abstracts journal	1 week	low
	General		
12	incoming post	2 h	low
	outgoing post	1 h	low
	Projects		
13	special information contract	1 week	high

Other work not included in the simulation study

Publications
- Sira Review
- Annual Report
- Press releases
- Research reports
- Brochures

Meetings
- At Homes
- Committees
- Special courses

TABLE 2

Activity categories involved in each demand category

Activity category	Demand category												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1									
2		2	2	2									
3	3	3	3	3									
4	4	4	4										
5					5	5	5	5			5		
6								6		6	6		
7					7	7	7	7	7		7		
8						8	8	8					
9												9	
10													10
11													11
12													12

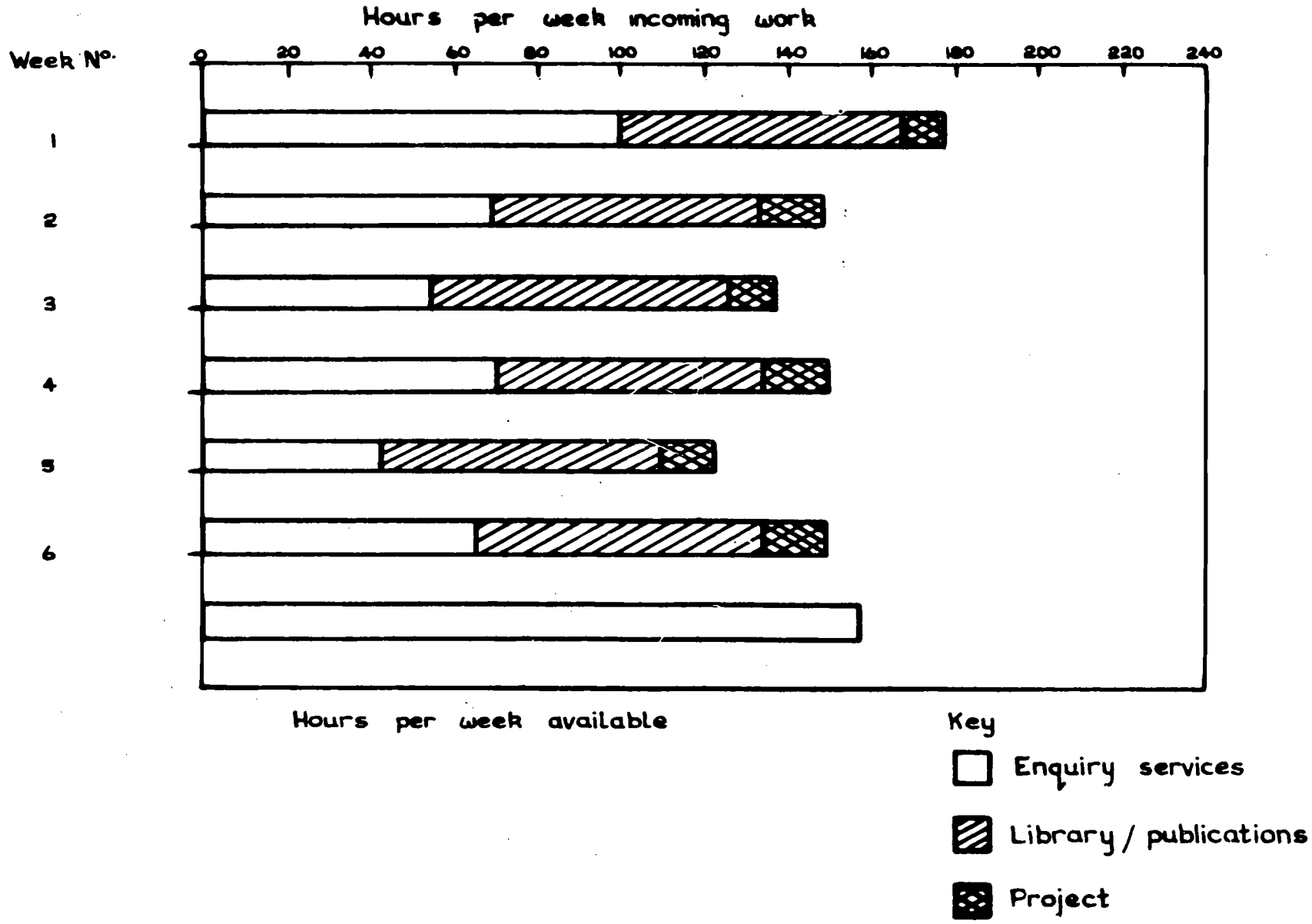

Fig 1. Comparison of incoming work with capacity senior technical work

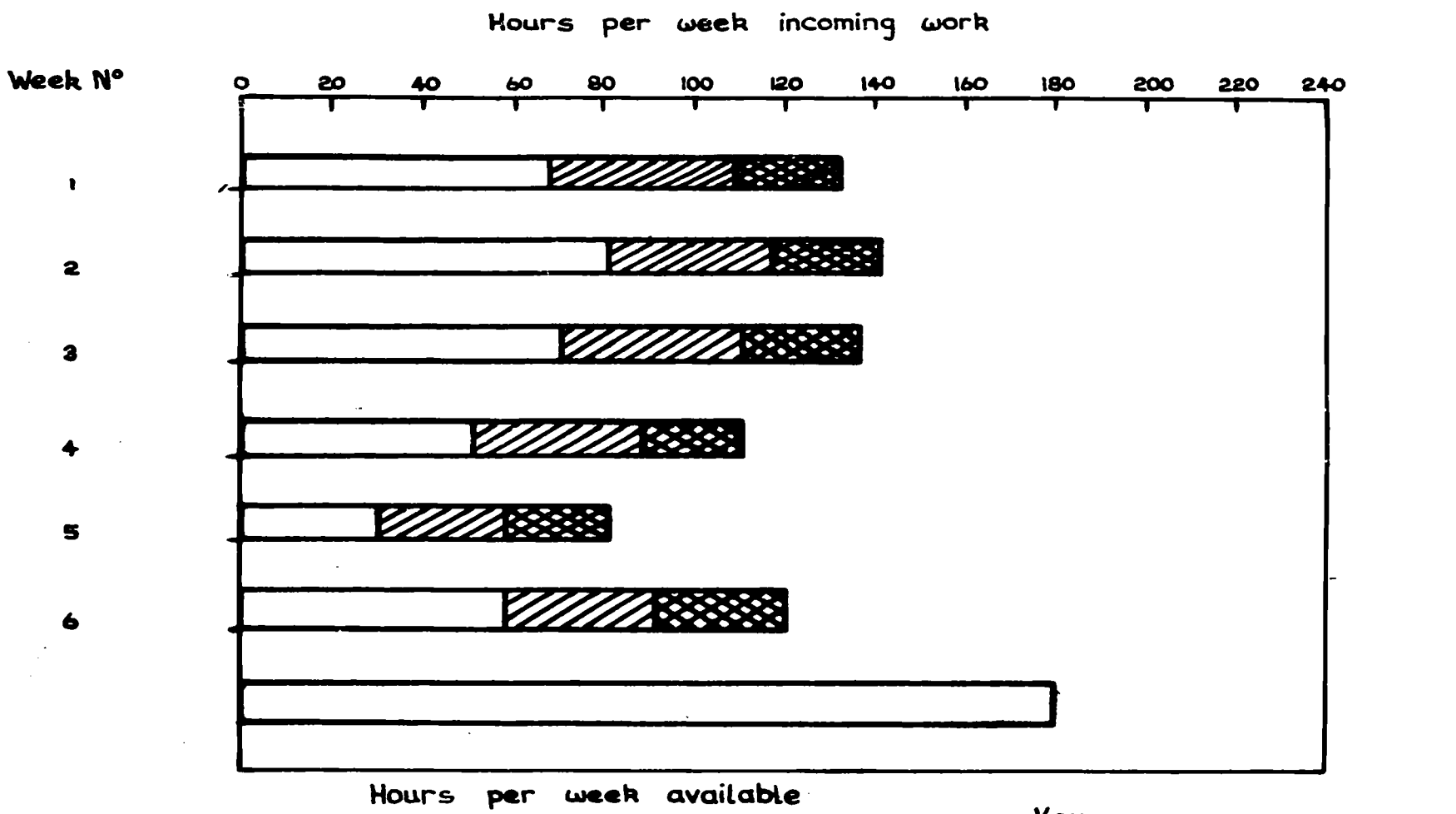

Fig2. Comparison of incoming work with capacity
Junior technical work

R454
Fig 2

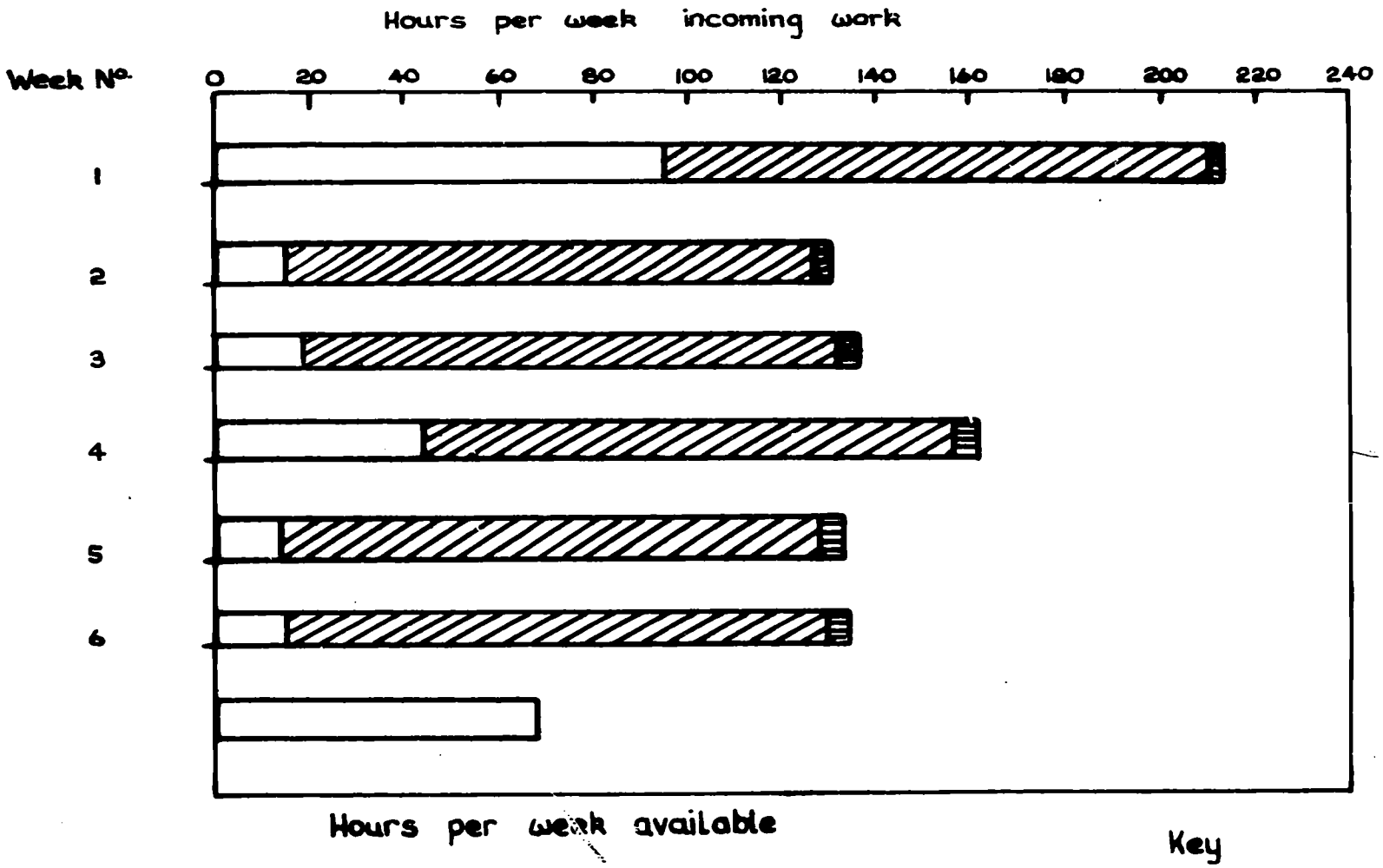

Fig.3. Comparison of incoming work with capacity
Clerical work

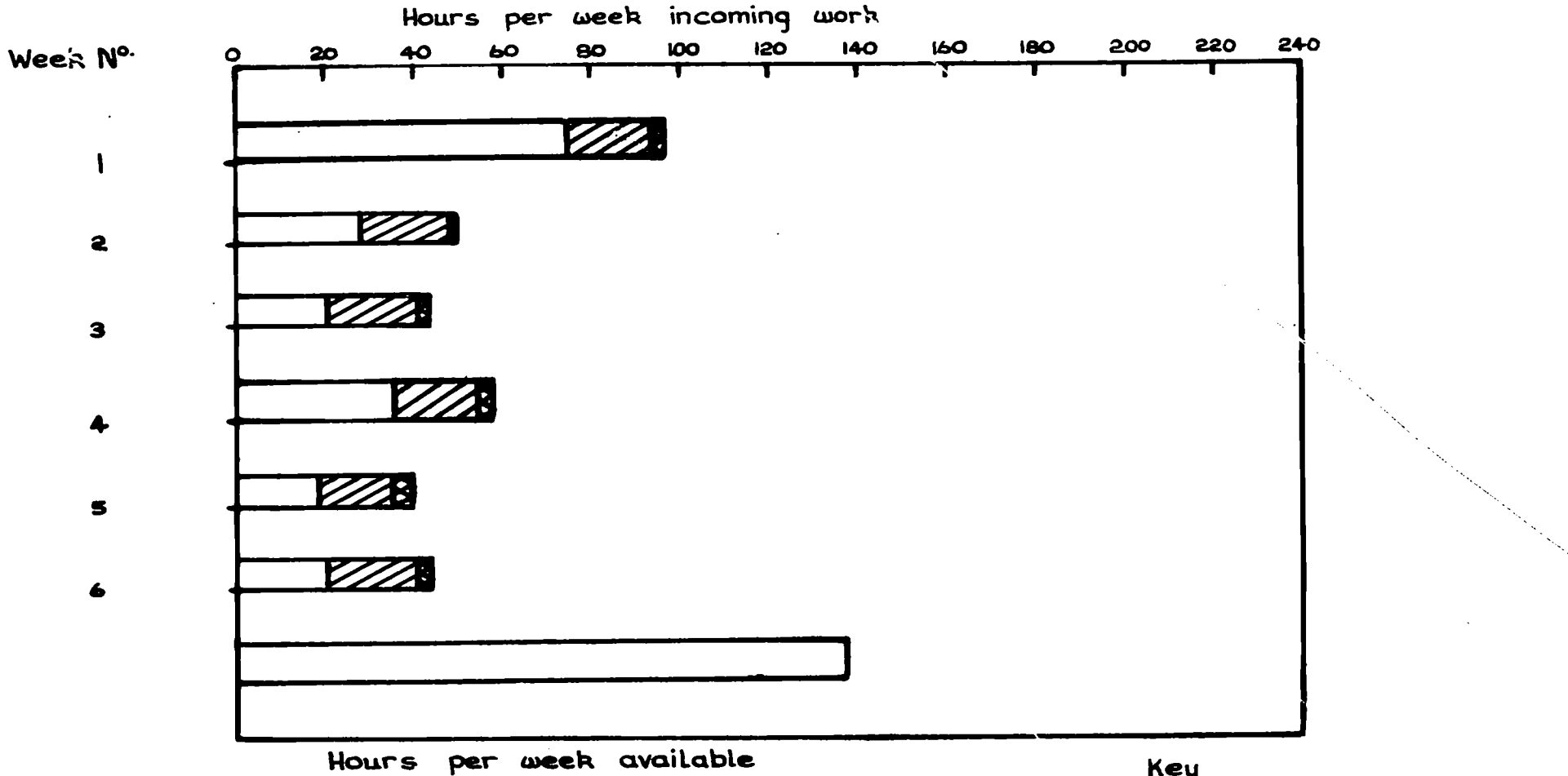

Fig.4 Comparison of incoming work with capacity
Secretarial / typing work

R&SA Fig 1

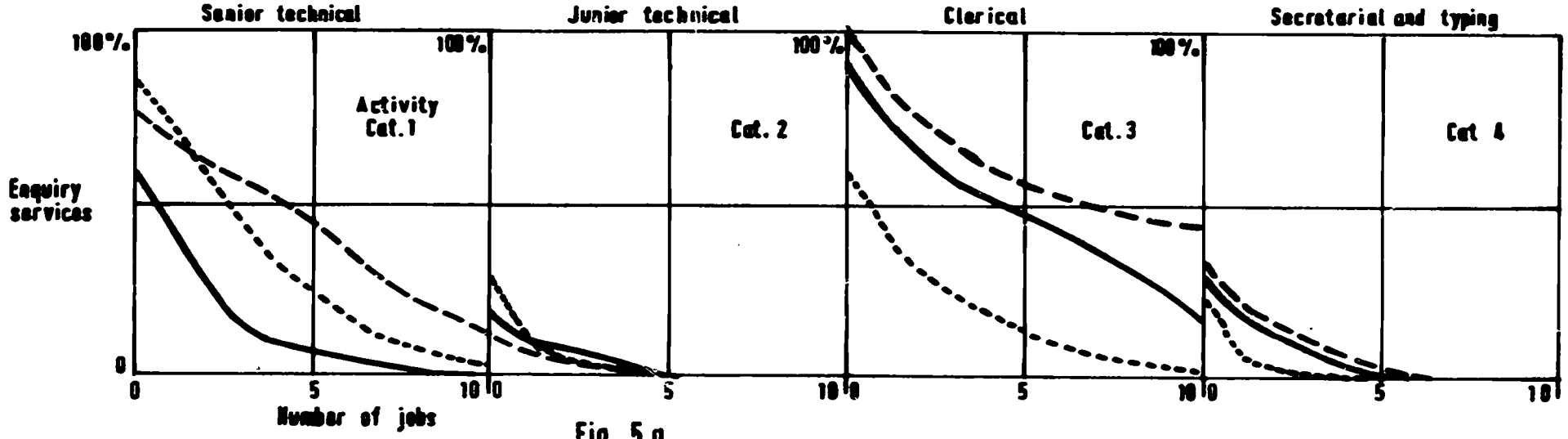

Fig 5a

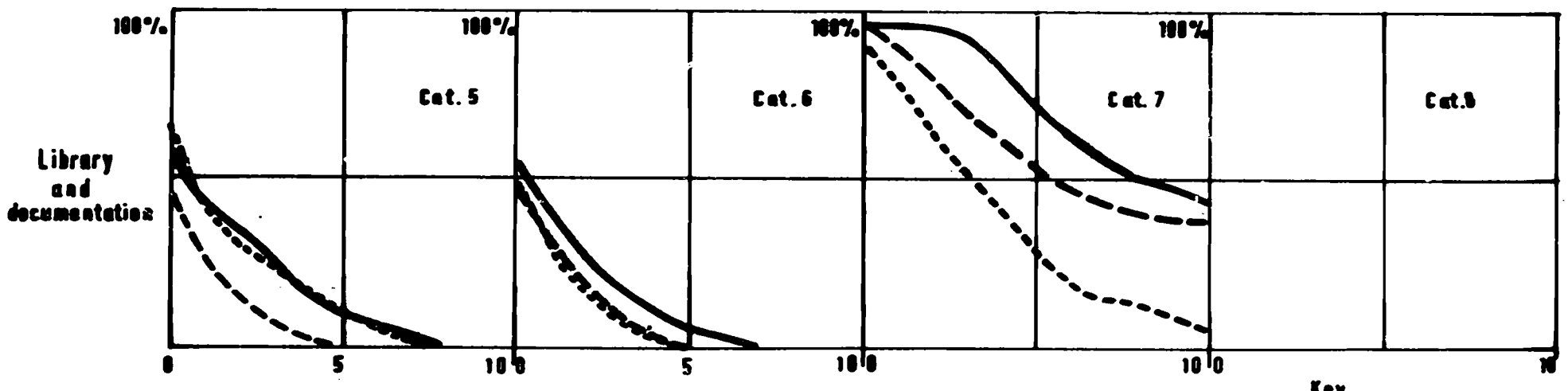

Fig 5b System bottlenecks

Note: No significant queues are generated in other activity categories in any of the three systems

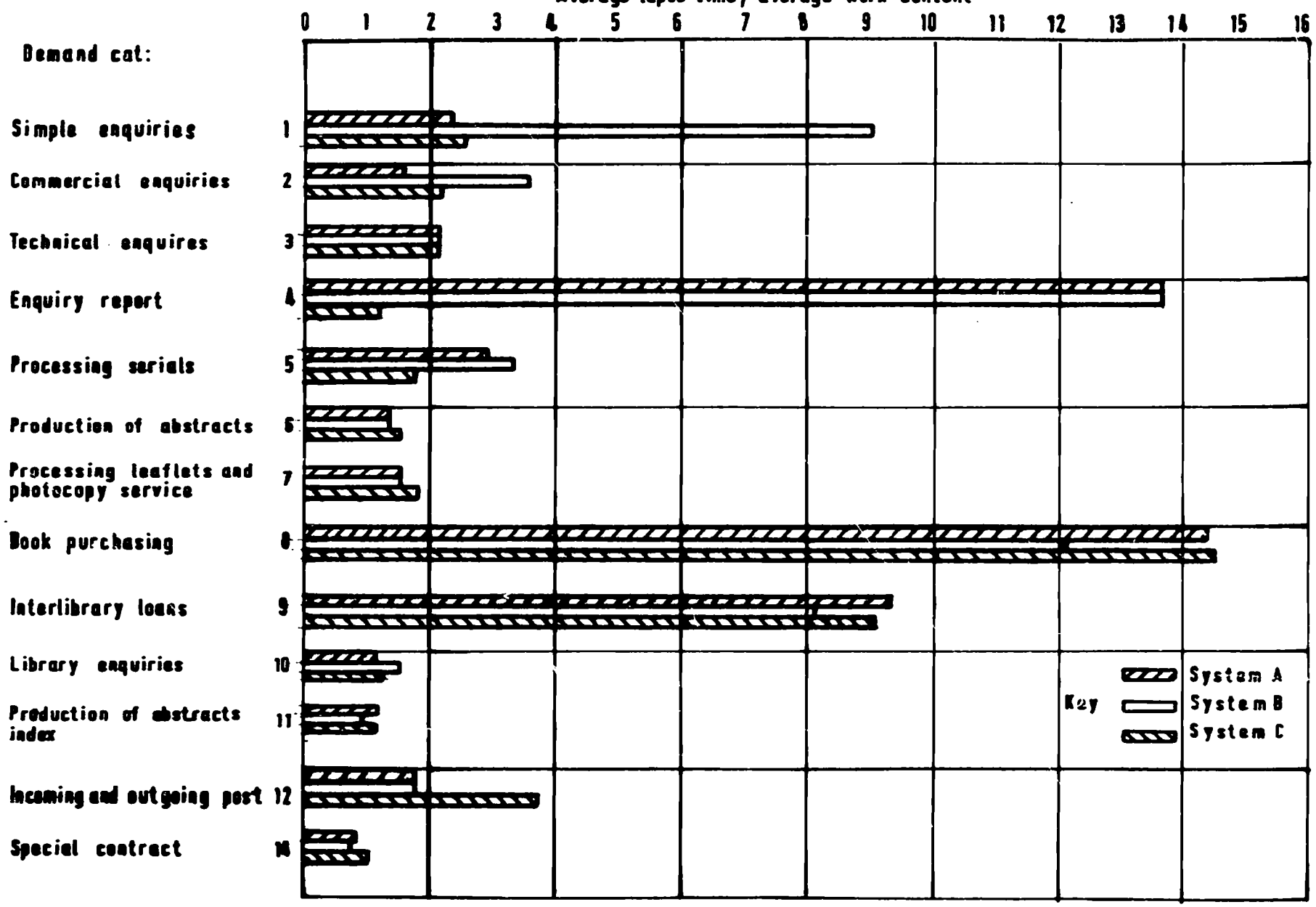

Fig 6 System response

RA54
Fig 6

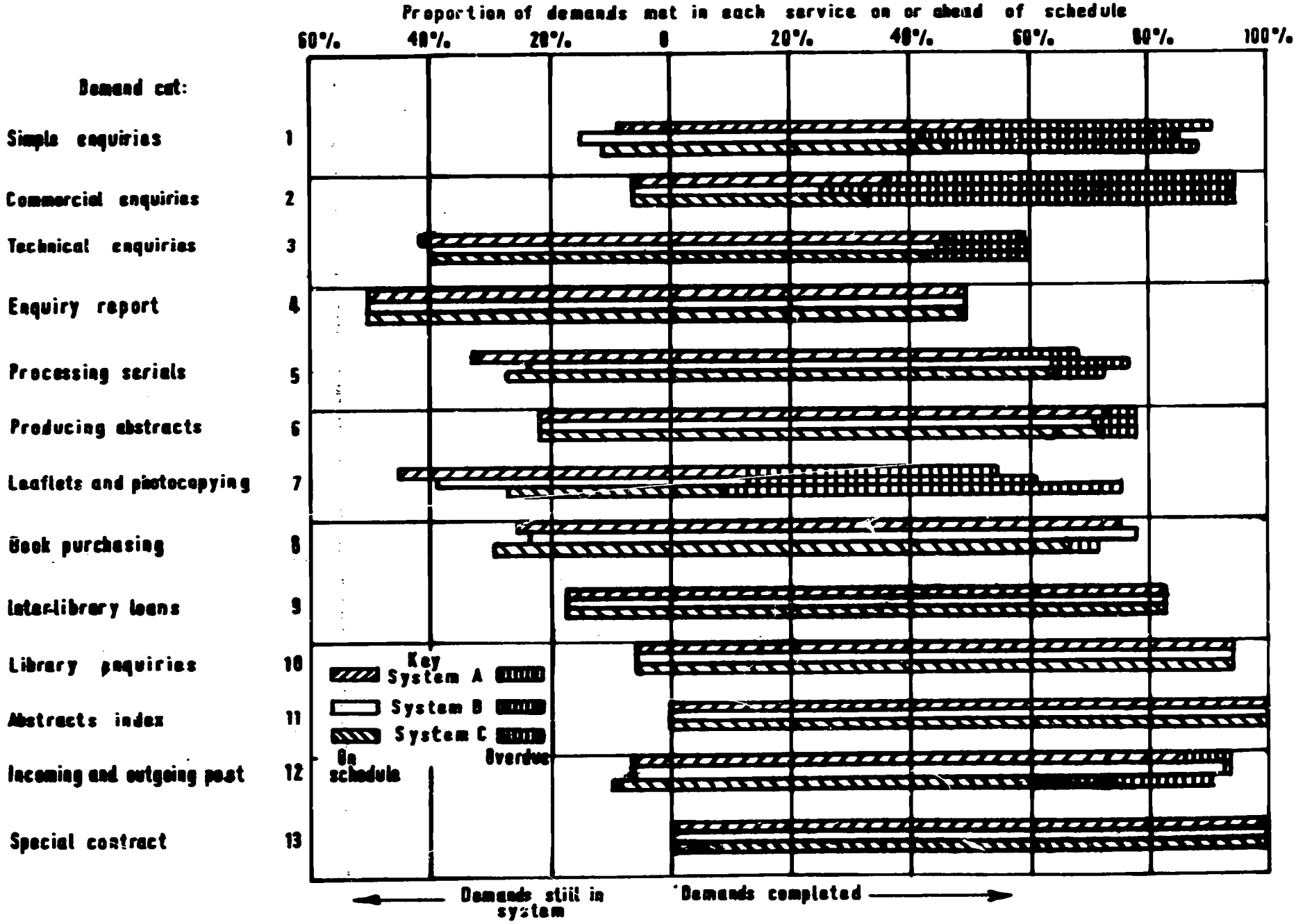

Fig 7 System performance

R454
Fig 7

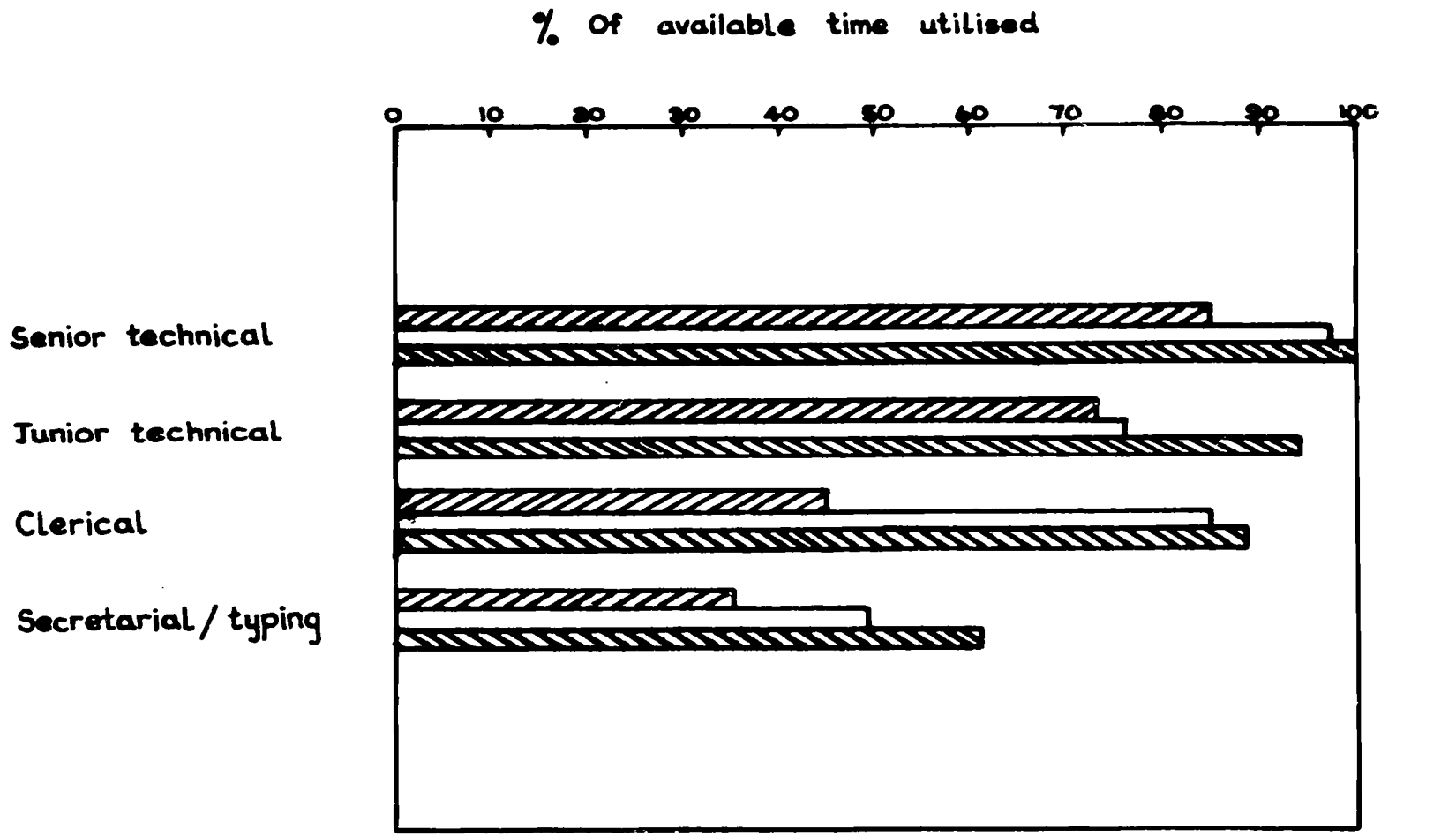

Fig 8. Utilisation of staff

R454
Fig 8

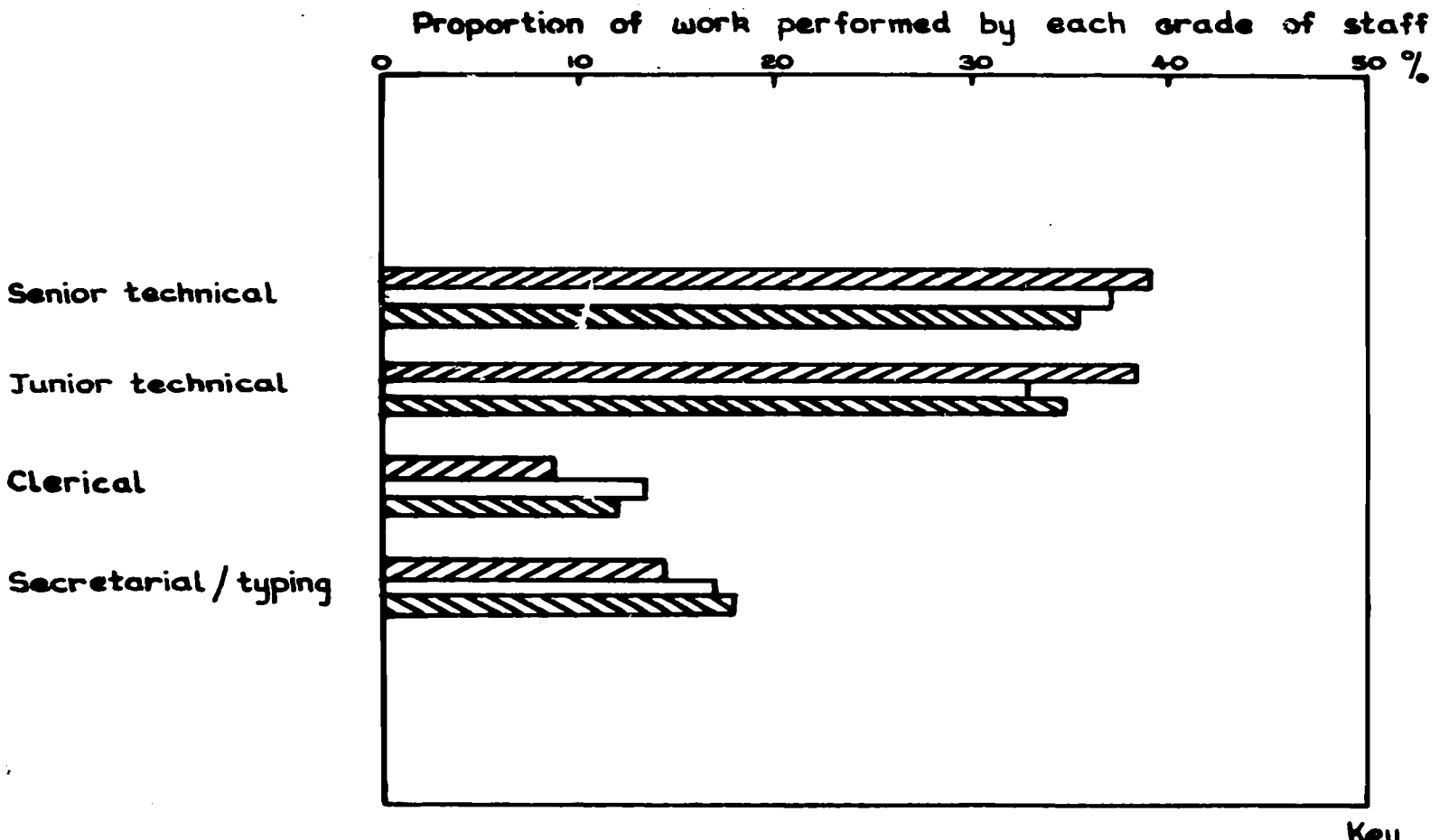

Fig 9. Relative utilisation of different grades of staff

R154 Fig 9

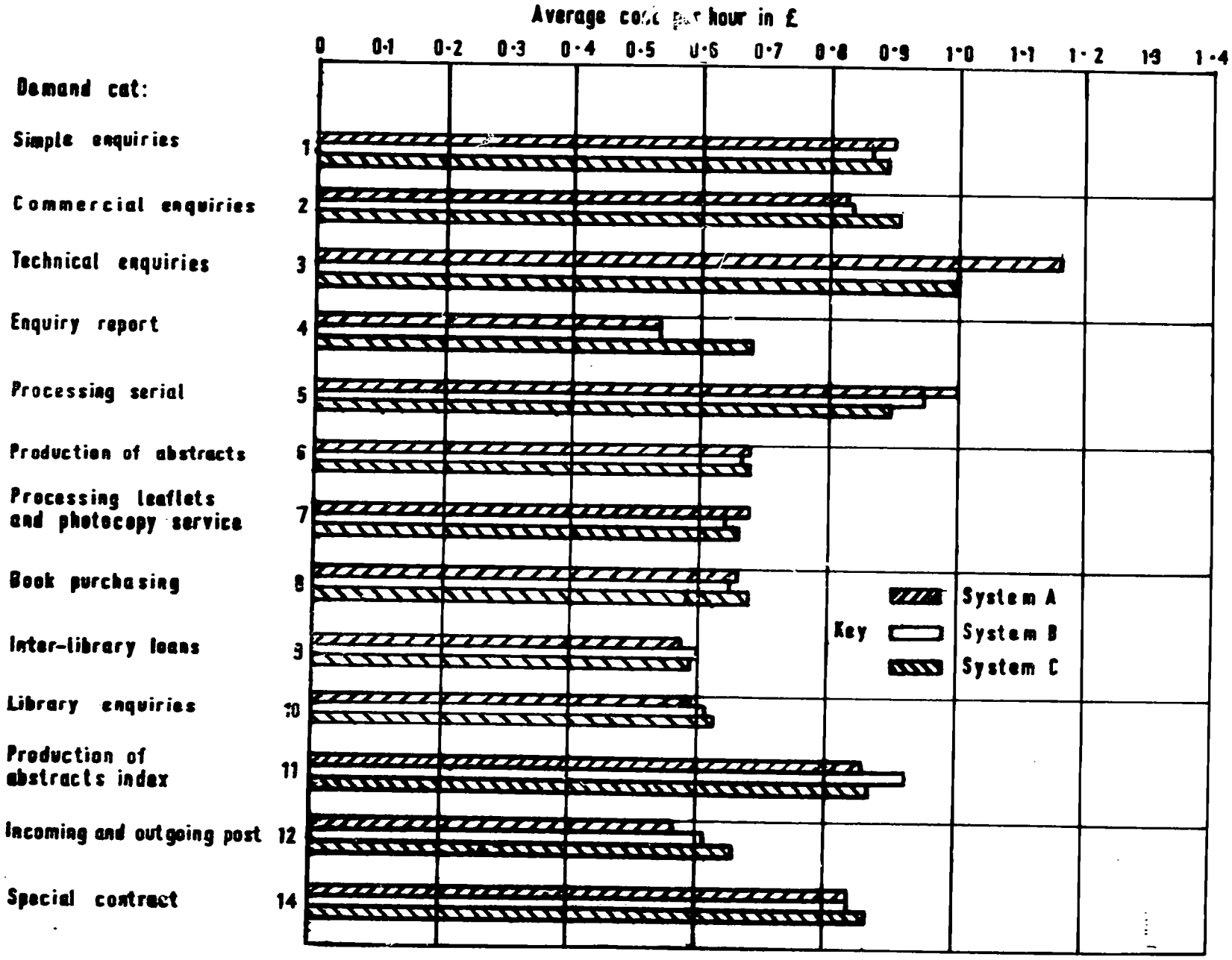

Fig 10 Service cost

R454
Fig 10

R454
Fig 11

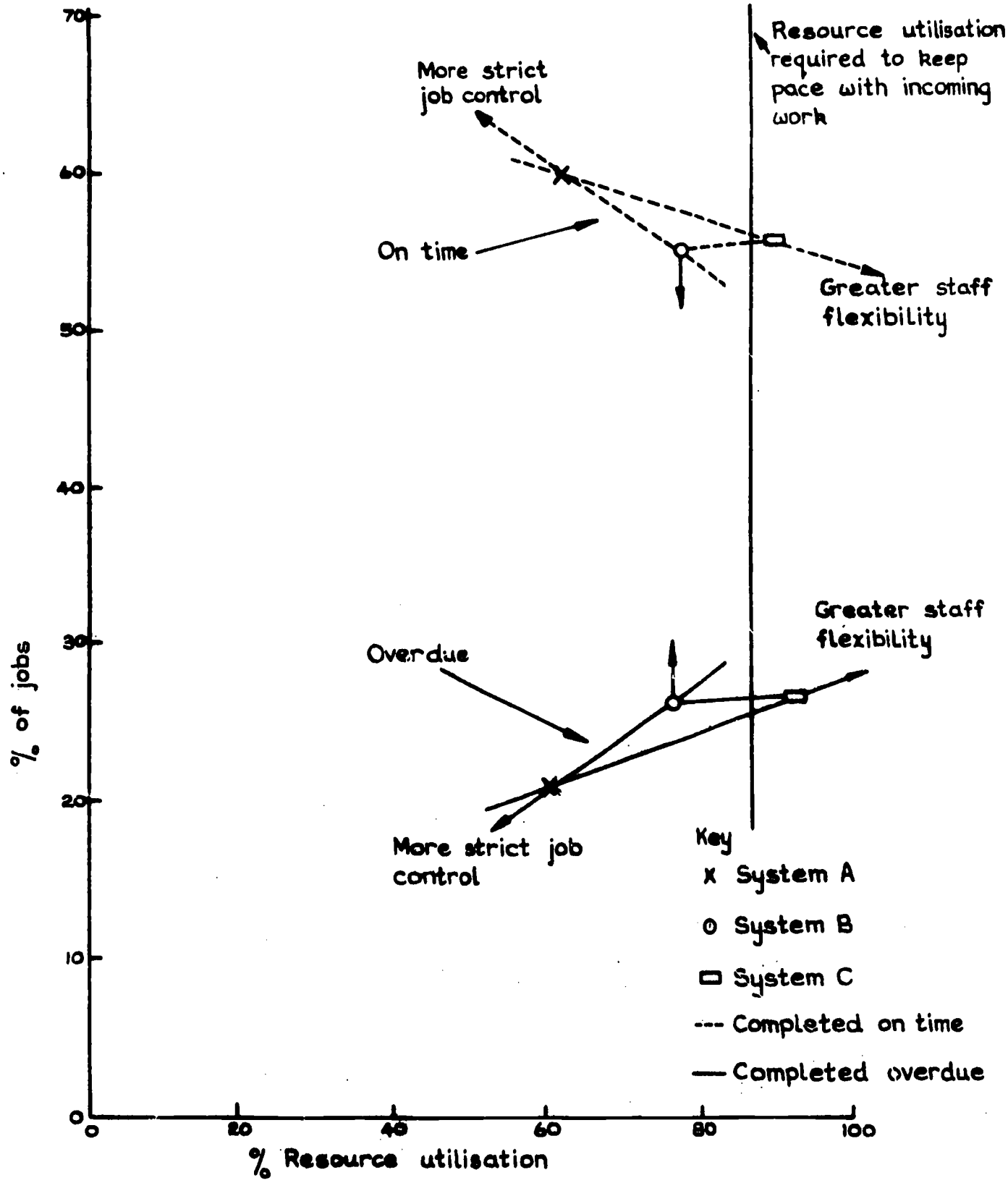

Fig 11 Performance v resource utilisation