The organization of a data link computing service

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The results of two years experience of using the Manchester Atlas via an off-line data link are presented. Towards the end of the period, traffic representing a Mercury computer was carried by the link, and an average turn-around of one day or less was achieved. Although technical faults developed in the link equipment occasionally, the main problems met were of an organizational kind, and the operating system eventually developed is described fully in the paper. The link has played a very important part in the expansion of computing at Nottingham University, and the organizational experience gained will be reflected in the systems adopted with the KDF 9 to be installed at Nottingham at the end of 1965.

1. Introduction

Nottingham is a medium sized university with approximately 2,500 full time students. Members of the university have been using computers at other centres since 1954, and after 1958 this use became extensive. Attempts to have a computer installed eventually led to the suggestion that Nottingham might take over a Mercury computer, but no money could be provided for the running and maintenance of Mercury and this, together with the approaching obsolescence of valve machines, led to the decision to instal a data link to the Manchester Atlas computer.

The data link was made operational with a grant of £5,000 from the UGC and £11,000 from a private source. This was used to purchase three Flexowriters and two ATE data link terminals, leaving just under £4,000 for the first year's running expenses. Manchester University undertook to provide us with facilities equivalent to one Mercury computer, though it was expected that Nottingham would not require more than half of this allocation until 1967.

The "Cripps Computing Centre" was initially set up within the Department of Theoretical Mechanics, and an operator was appointed in July 1963 to run the data link and punch programs for members of the academic staff. The Computer Director was appointed from September 1963; besides being expected to undertake and stimulate research in computing and its applications, his responsibilities include the organization of teaching at undergraduate and postgraduate levels in subjects relevant to computing, the establishment of a general advisory service in computing, the development of a library and general information facilities associated with the Centre, and the further development of computing facilities throughout the university.

The first few weeks soon revealed that the demand for computing-centre services was far greater than expected, a by now familiar university development (see for example Young, 1963). The punching service was discontinued, and the Computing Centre came to rely almost entirely upon outside volunteers to help provide lectures and other training facilities, advisory services, the batching and vetting of jobs for despatch by link or mail to Atlas, and the distribution of results among the many users. In spite of early frustrations and difficulties the workload continued to grow rapidly—detailed figures are given in Section 4 of this paper—and some of the organization techniques used to handle this volume of material are described in Section 5.

At Manchester, the problem was felt even more acutely, since Nottingham University is only one of many users of the Atlas there. The new computer was quickly surrounded by a saturation workload, but the figures of Section 3 reveal that—taking this workload into account—the performance of Atlas has been remarkably good. The link itself has proved reliable, except for occasional electro-mechanical failures that could have been avoided if funds had been available to purchase a spare reader and punch for each terminal.

2. Data link performance

The Nottingham to Manchester University data link comprises a GPO private wire, and ATE terminal equipment operating with Tally paper-tape readers and punches. The data link is "off-line"; program tapes are fed into the reader at Nottingham and are reproduced at Manchester in a room adjoining Atlas. An operator feeds these tapes to Atlas, and in due course output may be fed back to the link for reproduction at Nottingham. Jobs using a great deal of output request line printer (as described by Kilburn *et al.*, 1961); this is a faster output medium, but the results have to be mailed back to Nottingham.

The data link reads characters punched on 7-track tape, but transmits a 12-bit character to give an adequate redundancy check. Single bit errors are corrected automatically, and most multiple errors are automatically detected and cause transmission to cease. The terminals are connected by way of a "two-wire" circuit, meaning it is not possible to transmit and receive simultaneously; plans to complete the "four-wire" connection to each terminal—essential with "on-line"

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Table 1

Data link failures

PERIOD	WORKING DAYS	G.P.O. FAILURES ALL DAY	G.P.O. FAILURES HALF DAY	LINK TERMINAL FAILURES ALL DAY	LINK TERMINAL FAILURES HALF DAY
July–Dec. 1964	115	2	4	16	4
Jan–April 1965	82	0	0	2	5

working—have been abandoned since the two-wire circuit can handle all the demands which Nottingham are permitted.

Even with a four-wire circuit, it is not possible to exchange speech and data simultaneously. This situation is annoying at first, but as operators gain in experience they seldom talk except to exchange cryptic job summaries between batches of work. Tape changing, for example, can be anticipated; it takes approximately five seconds to put a new tape in the reader, and twenty seconds to thread a new spool in the punch.

A third switch in the telephone circuits associated with each terminal allows the link to be used to copy paper tape locally, and in fact it is used as a duplicating machine outside normal working hours. This feature is particularly valuable for checking purposes, as tape from the punch can be fed straight back to the reader providing a paper-tape delay line on which any errors will accumulate. The exhaustive checking of both terminals without too much human effort enables faults to be traced in the otherwise extended chain of communications.

Breakdowns

On occasions, a data link may be expected to fail completely, either through a major disruption of telephone services or total breakdown of either set of terminal equipment. Faults affecting transmission in the Manchester to Nottingham direction only have not been studied in much detail, as there is no risk of wasting a day's allocation on the computer—always a limit on the Centre's workload. Results can still be mailed, and although some users might be delayed there has seldom been a shortage of new work to transmit. Failure in the Nottingham to Manchester direction is more serious, and volunteer couriers are called upon to arrive at Manchester by train or car with a day's supply of tapes by 2.30 p.m.—the time at which Nottingham computing is scheduled to commence. A spare reader and punch would have saved many such trips, and would certainly have been provided had funds been available.

Table 1 gives a breakdown of faults causing total disruption of data link communications for all or half of a day. The two separate periods reveal an improvement in both line and terminal equipment. Not included in the table are temporary faults quickly repaired, e.g. occasional ten-minute failures of the telephone network, and failures of the Nottingham tape reader that could be quickly repaired. The terminal is maintained by contract with the manufacturer, but it is a simple matter to correct certain faults, e.g. to change an anti-residual shim in the tape reader—a part that wears quickly in working up to four hours a day with the Nottingham University workload. Electronic and more serious electro-mechanical failures (the former are rare—only three such faults have been recorded) have to be seen by a visiting engineer.

Detected errors

Fortunately the Nottingham to Manchester private wire is of good quality, and cessation of transmission due to detected errors is rare. When errors are detected, it is not possible to recommence without producing a faulty tape, and it is interesting to contrast the consequences when transmitting from or receiving at Nottingham.

If a program is to run satisfactorily on Atlas, it must be received intact and correct in every detail. Nottingham users wishing to transmit long tapes are required to leave occasional 6 in. stretches of runout where the tape can be easily spliced by Sellotape at Manchester. Short jobs are retransmitted, and to avoid cutting tapes unnecessarily all jobs are required to start with the legend ***A, which instructs the Atlas supervisor program to disregard any previous incomplete documents (Howarth *et al.*, 1961); Manchester University generously arranged not to charge such wasted sections against the Nottingham input time allocation. When output is received from Manchester, however, it is only necessary for the operator to retransmit about 6 in. of tape after a detected error; the user can easily repair the damaged tape if necessary. Similarly, with undetected errors, a far lower standard of reliability can be tolerated with a "data" link (receiving output) than a "program" link.

Undetected errors

With a good quality private wire, the terminal equipment manufacturers claim an undetected error rate of approximately 1 character in 10^6 transmitted, (10^7 with more recent equipment) i.e. 1 error in just under $4\frac{1}{2}$ hours transmission at the $62 \cdot 5$ characters per second operating speed. Again, it is the programming—Nottingham to Manchester—direction that is critical.

Taken over a number of months, the "average" Nottingham program is just under 10^4 characters long, so it would be expected that about 1% of transmitted programs would be affected, or perhaps a little less to allow for the effect of a distribution of program sizes; faults tend to occur mainly in the longer tapes. Very long tapes are usually mailed to Manchester, or established on magnetic tape, and this—coupled with the concise nature of the Atlas Autocode language—accounts for the comparatively small size of link-transmitted programs.

The undetected link errors that do occur seem usually to be caused by mechanical failures of the Nottingham tape reader or Manchester tape punch; the latter would, of course, be eliminated on an "on-line" system. Sometimes characters are completely missed; for example a badly punched sprocket hole may be missed by the photoelectric tape readers on Atlas. This will usually produce a program fault diagnosis; but it can be disastrous in the case of data tape, unless a programmer builds in suitable check procedures. Most faults, however, produce a "parity condition," a character with two, four or six holes—not permitted in the Atlas code. Atlas usually rejects such programs outright, but informs the operators so that they report the failure back to Nottingham. Typical parity faults are caused by misreading or mispunching one of the seven tracks; or a link tape reader may "miss a beat," slurring two characters together, or the punch may fail to advance and over-punch two successive characters into an "or" combination of even parity—both symptoms of a worn stepping motor.

Unfortunately, it is not always easy to trace the cause of tapes being rejected by Atlas, as many other faults may cause no output to appear at Nottingham. Operators may lose tapes, the original tape may have parity faults or bad spacing caused by faulty use of the Flexowriter or other equipment, or certain information in the job heading or job terminators required by Atlas (Howarth *et al.*, 1961) may be incorrectly formulated, or a job may be lost through an Atlas breakdown, or a short output tape may be missed among the great quantities of tape handled at Nottingham. During a recent sample period, when for checking purposes the input tapes at Manchester were mailed back to Nottingham, 36 programs were lost out of 491 transmitted, i.e. 7·3%. Detailed examination revealed the following causes:

Faults on original tapes	17
Data link errors	5
Operator errors	2
Possible Atlas errors	9
Not known	3

Usually about 10% of Nottingham jobs fail to produce output, so the period sample was a little better than average. Possibly the data link does not always achieve the target 1% figure. During the earlier days, over 20% were sometimes lost, but the figure was improved by the stricter vetting of jobs accepted for transmission by the Computing Centre.

Flexowriters are slow tape-editing machines, and users with large tapes often wish to splice them—e.g. to add a new set of data to a working program so that the job can be transmitted in one piece to Manchester. Atlas uses 7-track odd parity code (to include erases). Blank tape is not allowed, so runouts between sections of program usually consist of upper-case characters—three holes punched. Since the link tape reader is mechanical, it is not sufficient to cover the sprocket holes with opaque Sellotape to skip blank characters. Programmers must therefore punch a hole—usually the Newline character—through the spliced tape; unless this is done with extreme care a data link tape reader failure is easily produced.

Table 2

Comparison of Manchester and Nottingham Atlas Computing Service

FRACTION RETURNED	MANCHESTER UNIVERSITY	CRIPPS COMPUTING CENTRE
Same day	33%	48%
Next day	62%	40%
2 or more days	5%	12%

3. The Atlas computing service

The Atlas computing service is dominated by a saturation workload; Nottingham's time allocation, for example, could be easily used twice over by quite reasonable programs. A simple theoretical model of the resultant service has been suggested as follows:

Twenty-four hours work—remembering that Manchester University has only a half share in Atlas—is accepted by the computing service during an 8-hour working day. One-third of this can be run during the day, so users are allowed to mark one-third of their work for priority treatment. The remaining two-thirds is run at night and returned the next day, suggesting an optimum average turn-around of 0·67 days.

To avoid difficulties in sorting large quantities of paper tape, Nottingham is scheduled to start computing at 2.30 p.m. (Data Transmission Handbook, 1964). Jobs that cannot be run by about 3.30 p.m. are returned to the night queue. Figures compiled independently for Manchester University and the Cripps Computing Centre during a sample month both yield a mean turn-around of 0·75 days, but the detailed distributions reveal that Nottingham had more jobs run the same day (see **Table 2**).

In **Fig. 1**, a summary is presented of the monthly mean delay experienced by Nottingham University programs in the Atlas computing service. Saturdays have been included in the delays, and as there is no Saturday computing service, the minimum saturated model service figure becomes 0·8. On several months this figure has been bettered, because of the generous day-time allocation. Long delays in December 1963 and May 1964 were caused by too much work being accepted at a time when Atlas was unserviceable.

A detailed histogram of these delays is shown in **Fig. 2**, where the shaded areas represent in magnitude the fraction of the work returned each day. The serious breakdowns account for long tails on the monthly distribution. In the early days, the data links had no special daytime allocation, and jobs were seldom returned the same day.

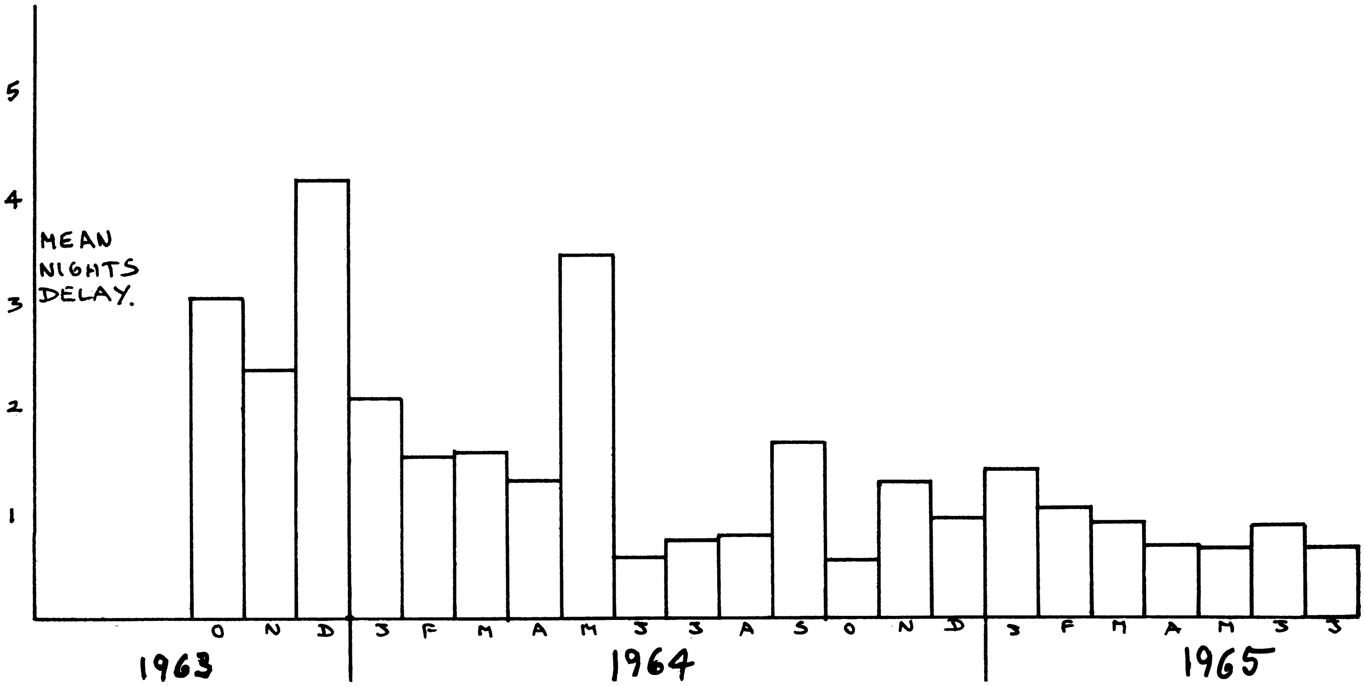

Fig. 1.—Average turn-around times experienced by Nottingham programs

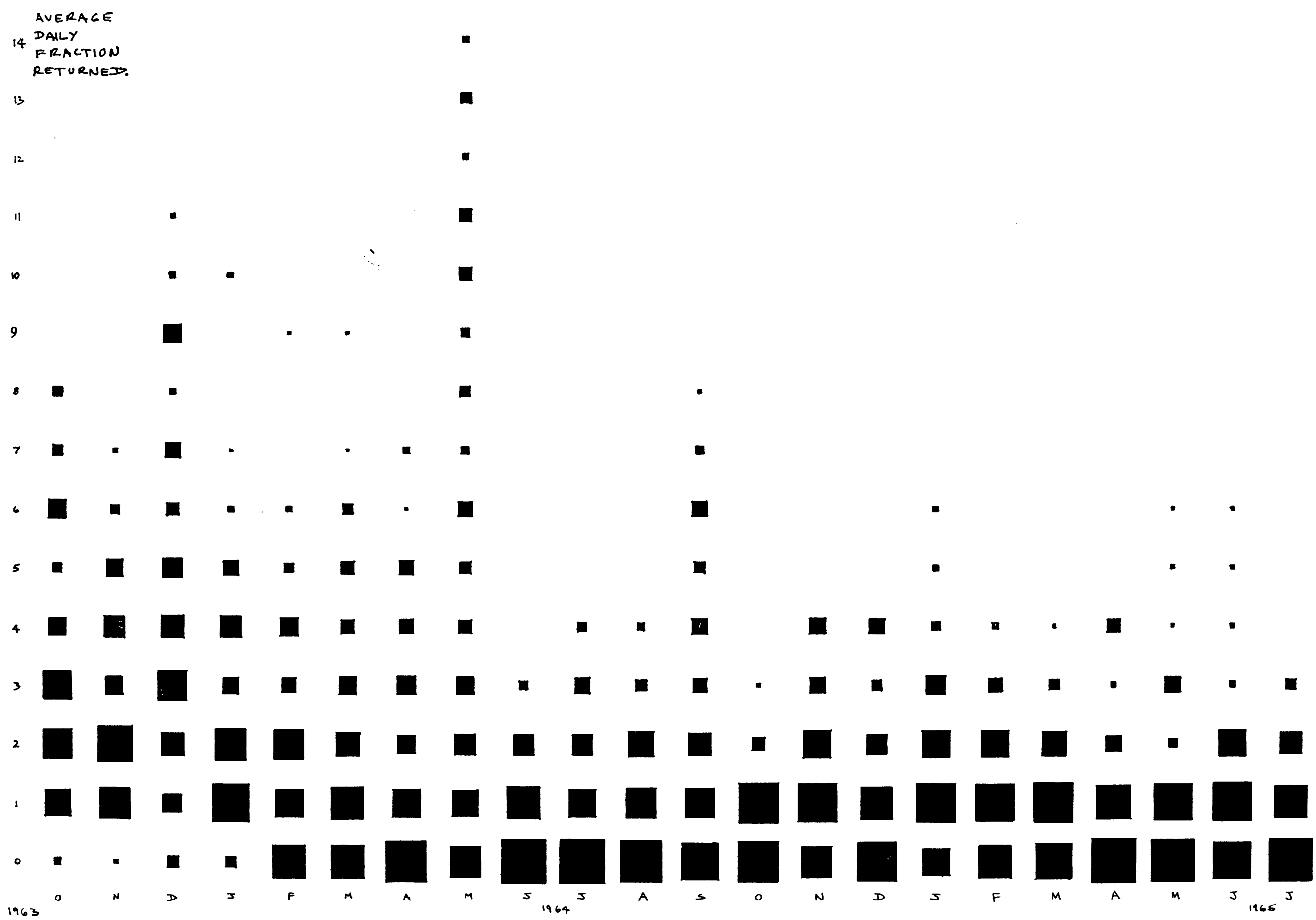

Fig. 2.—Detailed monthly distribution figures yielding the mean turn-arounds of Fig. 1; the shaded areas indicate the fraction returned each day

It is also possible to define an "apparent delay" to include the effects of waits for transmission from or to Nottingham, and to the occasional equipment failures described in the previous paragraph. Even with an all-daytime allocation, a user cannot expect more than one turn-around a day. Attempts have been made to achieve two, but it is difficult to schedule this into an 8-hour day leaving sufficient time for a programmer to digest output and to prepare a new tape. Accordingly, it is necessary to add one day to the mean figure to indicate that—say—five runs a week cannot be bettered except by privileged arrangement. Then, to account for equipment failures, we may define: "apparent delay" = (1 + mean delay)/(1 − chance of an equipment failure). In terms of this figure, it turns out that even the most experienced programmer should allow a month for the development of a large and complicated program requiring perhaps ten debugging runs. It takes about five runs to develop a small routine, and anxious users may develop four or five such routines simultaneously. The routines are then established into a complete job, the resultant large tapes being particularly prone to link faults.

Time allocations

The Nottingham time allocation on Atlas is measured in three parts: (i) computing, 20 minutes at 3 microseconds per operation (except that multiplying counts 2 and dividing 4). (ii) 30 minutes input at 300 characters per second. (iii) 60 minutes output at 110 characters per second, or equivalent use of the line printer taken as though there are 35 characters to a line.

In order to provide a reasonable "job mix" for the Atlas system, the allocation is judged to be used when any one part is used, and care has to be taken in rationing the Nottingham users to make the best possible use of this allocation. On average, the allocation proves to be slightly output limited, so jobs requesting more than 300 lines of line printer output or 3 blocks (about 1,200 characters) of paper tape are refused except in very special cases. Input usually runs at about 85%. There are often plenty of large jobs requiring much computing, in spite of hand-coding loops to cut the computing time in half; the Centre accepts as many as possible without risking the input/output allocations.

As soon as summary figures have been compiled by Atlas, the Manchester operator reports them to Nottingham, where they are displayed. Each output tape from Atlas yields detailed information of input, output, computing, compiling and magnetic-tape time used, and a log of these helps check an accurate job mix. With reasonable care, it is possible to accommodate between 60 and 80 programs a day. Both universities follow a policy of refusing to accept more work than can be accomplished each day—the only way to avoid building up enormous backlogs of waiting jobs.

Atlas jobs are costed separately for input, computing and output according to a standard I.C.T. formula; Nottingham University pays at one-fifth rate. The industrial charge is roughly 1d. for 20,000 instructions obeyed (about £4 a minute), 3s. to read a "block" of about 4,000 characters of paper tape, 5s. to punch a block of paper tape, and ½d. a line for the printer. There is a small additional charge for storage and for use of private magnetic tapes. Monthly statements are drawn up by the machine, and in due course charged to the individual Nottingham departments using it.

It is necessary for a satellite centre to employ its own full-time operator at the parent computer. This operator receives programs, runs them on the computer, transmits or mails output, and reports regularly on the operational state of the computer and other equipment, on the allocation usage, and generally looks after the interests of the satellite centre. Originally, Nottingham University paid a one-quarter share of an operator's salary, but this proved inadequate.

Recently, the Science Research Council (SRC) Atlas computer* at Chilton has come into operation, and attracts jobs that can wait the extra two days for postal services; undergraduate training programs and very large production runs are sent to Chilton, there being no charge on that machine for university work. In addition, 40 or 50 of the 150 active users of the Cripps Computing Centre have visited Chilton to speed program development (though never more than two at one time). With this additional outlet, it has been possible to relax very slightly the stringent rationing conditions imposed upon Nottingham computing projects.

4. Computing Centre workload

The rapid increase in demand for computing facilities following the installation of the data link at Nottingham is indicated by **Fig. 3**, which shows the monthly average number of programs sent per day (excluding breakdowns) from Nottingham to Manchester. The early figures—shown by broken lines—are based upon the Manchester accounts; no accurate records were then kept in the Cripps Computing Centre.

The histogram starts with a rapid increase—a phase of recovery from having no organized computing facilities available. The Manchester allocation was increased several times to permit this expansion, but final saturation was achieved by May 1964; in fact, it became necessary to cut the load to achieve a more reliable service and a faster turn-around. In particular, all undergraduate training programs were stopped at that time, together with less urgent research projects.

The figures after June 1964 indicate computing capacity available, rather than demand. An extrapolation of the earlier months reveals a potential doubling of the workload carried by the end of 1964. The shaded area represents jobs mailed from the Computing Centre to Chilton. Four remote departments at the School of Agriculture mail their own tapes to Chilton, and together with two visiting programmers contribute an additional workload of 10 or 15 programs a day not

* Formerly known as the N.I.R.N.S. Atlas computer.

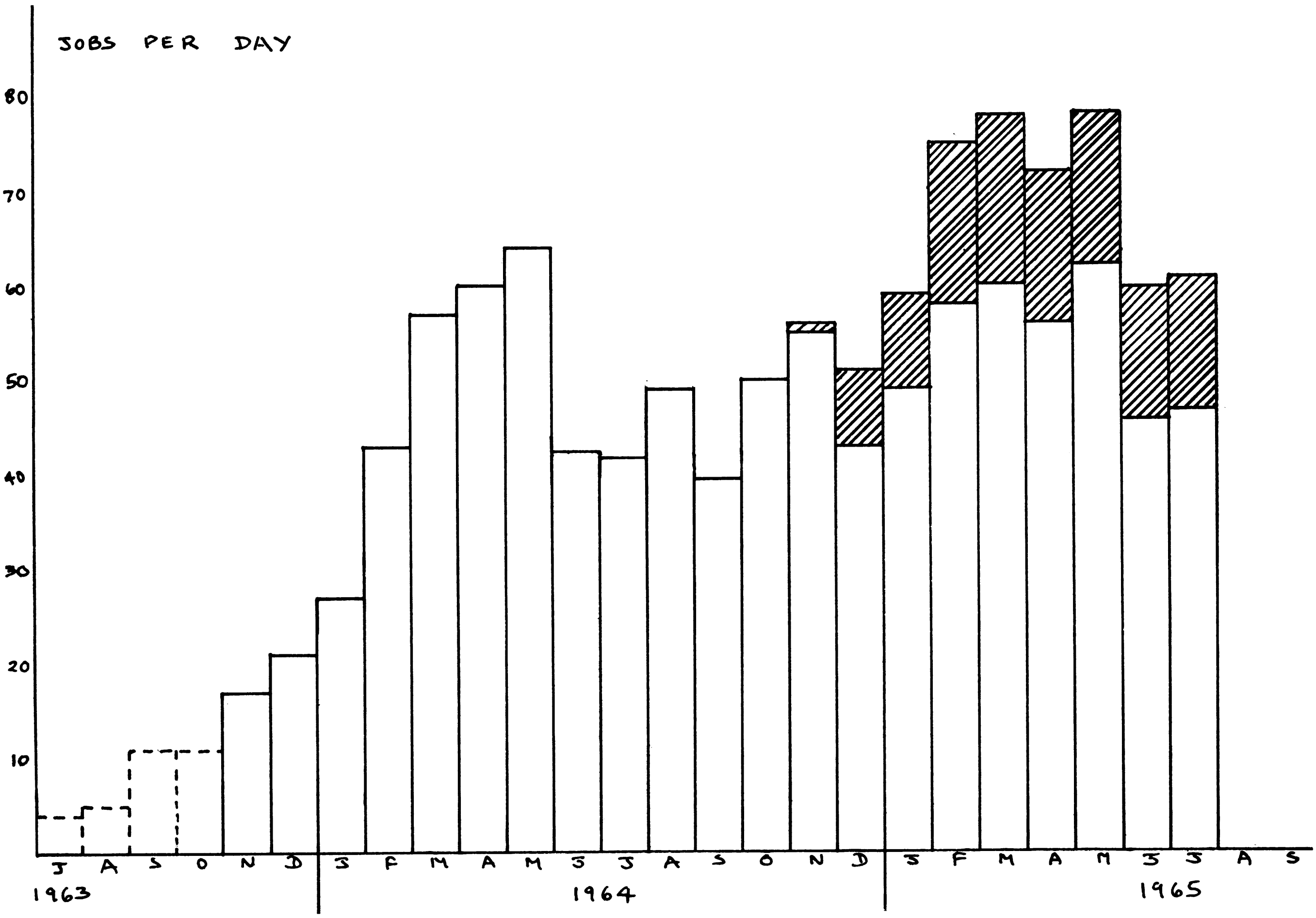

Fig. 3.—Average daily number of programs sent from Nottingham to Manchester and (shaded area) Chilton

shown in the figures. Even without the Chilton facility, it is apparent that some increase has been achieved during recent months, mainly through improvement in the Atlas supervisor arrangements. Note, too, that there is very little correlation between the university demand and the academic term (Buckingham, 1960).

From the detailed records maintained in the Computing Centre it is possible to estimate the number and size of jobs run by the different departments of Nottingham University as listed in **Table 3.**

It is interesting to compare these figures with figures published for London University (Buckingham, 1960) 30% Physics, 25% Crystallography, 20% Chemistry, 12½% Statistics, 7% Engineering, 3½% Applied Mathematics, and 2% Others. The Applied Sciences form a particularly important part of the Nottingham workload. When it became necessary to cut the load in May 1964, departmental allocations were introduced at Nottingham, tending to freeze the departmental computing structure. Subsequent increases have been taken up mainly by other departments (including the Computing Centre, external customers, Geography, Agricultural Economics, Agricultural Sciences, Psychology, Social Sciences, Law, Education, Theoretical Mechanics, Institute of Education, and the Registrar's and Bursar's departments). Some 27 departments of Nottingham University now use the computing facilities offered by the Centre, and provide a population of over 150 programmers (excluding undergraduate and other teaching activities).

One figure of particular interest is the fraction of total computing time used in compiling Atlas Autocode programs—the ALGOL-type language adopted in Nottingham to make the best possible use of Atlas. Atlas compiles programs afresh on every run, except for occasional users storing lengthy programs on magnetic tape; this is not unreasonable, since it has been estimated that 80% of the jobs transmitted are in the development stage. Weekly figures compiled over the last eight months of 1964 vary between 21% and 42% of computing time used in compiling, with a mean 32%. There is an Atlas ALGOL compiler, but this is less efficient. Atlas Autocode also has extensive built-in facilities, including matrix and differential equation routines, complex arithmetic, and excellent error-diagnostic arrangements that make it particularly well suited for data-link use.

Further detailed information on the changing univer-

Table 3

Average departmental jobs

DEPARTMENT	PERCENTAGE OF TOTAL BY NUMBER: 6TH APRIL TO 5TH JUNE 1963	6TH JUNE TO 17TH OCT. 1963	AVERAGE JOB SIZE: INPUT BLOCKS	OUTPUT BLOCKS	COMPUTING TIME (SECS)
Mechanical Engineering and Fluid Mechanics	24·8	23·7	2·2	3·3	14
Electrical Engineering	18·2	19·8	1·6	1·7	23
Civil Engineering	9·5	8·7	3·1	3·3	9
Physics	7·1	8·8	2·2	2·4	8
Chemical Engineering	6·5	6·1	1·4	1·4	5
Mining Engineering	4·9	7·0	2·2	2·9	18
Mathematics	3·6	4·7	2·5	2·6	11
Chemistry and Crystallography	3·4	3·7	8·3	4·9	40
Agriculture	2·6	3·5	3·7	3·3	13
Horticulture	2·5	2·4	3·8	2·0	14
Economics	2·1	5·8	3·4	2·7	18
Zoology	1·5	3·8	1·9	1·6	3
Teaching	11·6	Nil			
Others	1·7	2·0			

sity workload is revealed by the accounts prepared by Atlas for costing. **Fig. 4** shows the monthly average cost per job. The cheapness of the Atlas computing service offered is revealed by a glance at the ordinate; it has been estimated that to recover Computing Centre equipment, maintenance and salary charges at Nottingham it would be necessary to charge at least £1 a job, yet they are run through Atlas for about 10s. In order to discourage jobs unsuitable for Atlas it proved necessary to introduce minimum charges, initially 3s. including a 1s. handling charge, later 5s. with no handling charge (we had then appointed our own operator), shown by a broken line in Fig. 4.

An early feature of Fig. 4 is a steady reduction in job cost, attributed partly to increasing skill in the use of the machine. At first, programmers were reluctant to impose strict job heading limits (Howarth *et al.*, 1961) on untried programs, but expense soon led to improvement, subsequently extended by use of more sophisticated numerical techniques and hand-coded loops, until the load became saturated by input and output rather than computing time. Particularly low figures in 1964 reveal a high proportion—10 or 20%—of undergraduate training runs at the 3s. minimum charge. Costs then tended to increase as programs were developed for more serious computing, until the SRC Atlas attracted some of the more expensive work.

The detailed departmental breakdown of the monthly Manchester bill—excluding handling—is shown in **Fig. 5**; for convenience, the four agricultural departments at Sutton Bonington have been summed. Some departments with outside contracts purchase time at the full industrial rate, through Manchester University or through the alternative I.C.T. computing service. The former is included, but the costs are all transformed into equivalent university rate in order to present a true picture of the departmental loads. The graph shows the introduction of new departments. It is also interesting to observe the relative stability of the different departments' workload.

In recent months, the figures may be adjusted to take account of the use made of the SRC machine. For example, in May 1965, had we been charged at the Manchester University rate for use of the SRC machine, the Chemistry Department fraction would be increased from 1·7% to 3·7%. The shares of Mechanical Engineering, Chemical Engineering, Mathematics, Agriculture and other departments are increased, Economics is unchanged, and the other departments are decreased showing that they tend to depend on Manchester alone.

5. Computing Centre administration

With very limited staff, and with the extra difficulties of using a remote computer by way of the extended data-link chain of communication, it was necessary to take considerable pains in setting up the administrative procedures concerned with the preparation and running of computer programs in the Cripps Computing Centre; the system described in this section was gradually evolved as deficiencies became apparent.

A tape is first prepared for running by the user, who is responsible for punching (or having his secretary punch) his own tape, complete with job heading and terminating characters. Additional rules are imposed by the Cripps Computing Centre for ease in handling tapes, for example the title must follow a standard pattern denoting the university (UNOTT), departmental code, a single user's name and an identification number not exceeding six characters in length; to avoid confusion, this identification number is changed on every run. The tape ends with an arrow pattern, ignored by the computer but easily recognized by the operators.

The user must write his name and number at the start of the tape, to avoid possible confusion when re-winding after transmission. The tape is placed in a box of suitable size, and a clean printout of the job heading is Sellotaped to the box. The job heading—the first part of the program presented to Atlas—contains all the information required by the operators, so there is no need for any form. The job is then placed in one of two trays in the Computing Centre, labelled Tape Output and Line Printer Output. Whenever possible, Nottingham jobs are sent by data link, but users are advised to keep previous copies of their programs in case there is accidental loss of or damage to the tape.

The trays are emptied by the Computing Centre staff, and except for very long jobs are sorted into batches of six—a convenient size for handling by the Manchester operator. The arrow pattern is important, so that in

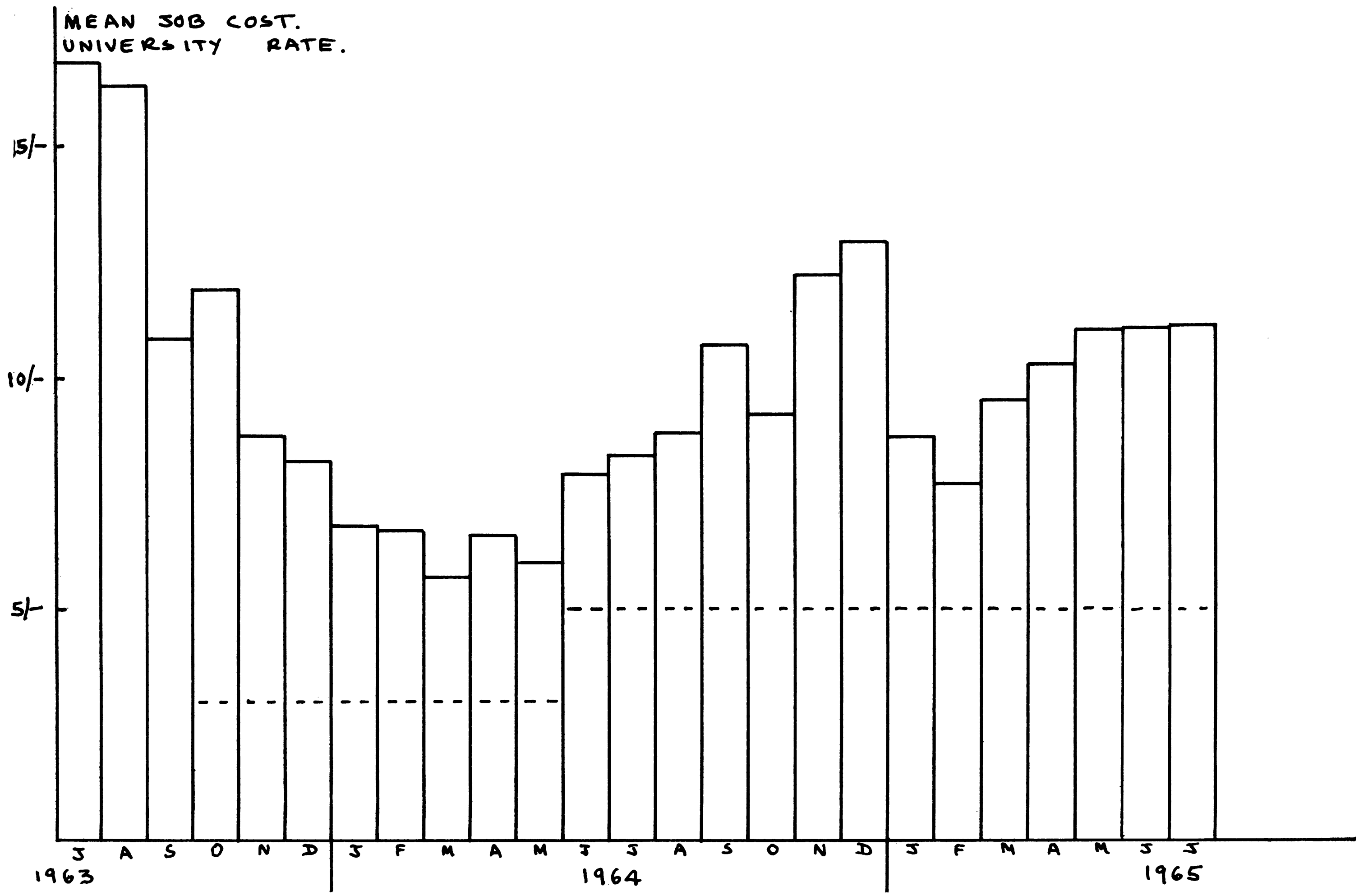

Fig. 4.—Average university-rate job cost

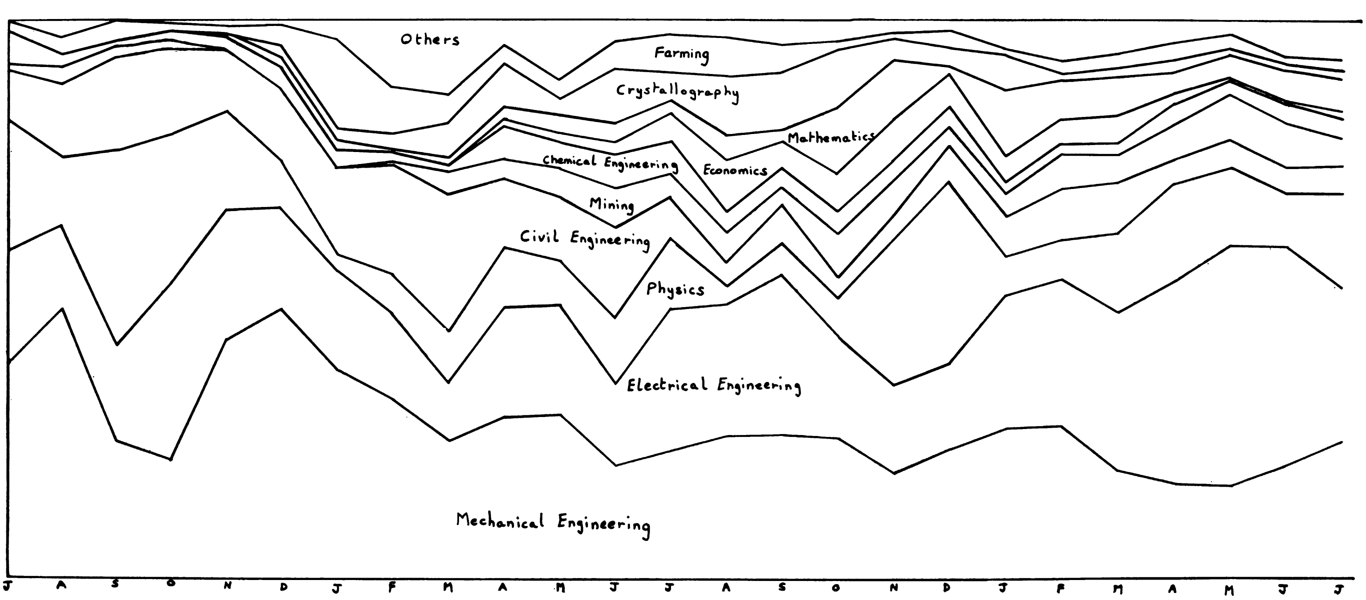

Fig. 5.—Relative computing charges incurred by different departments

Table 4

Computing centre log

NUMBER	LINK?	BOX	INPUT	DEPT.	NAME	TITLE	COMPUTG. 1000	OUTPUT	LINES	COMPILER	PRIORITY	DATE REC.	LINK?	INSTR. COUNTER	COMPILE	STORE	INPUT	OUTPUT
6861	L	2	7	MATH	NEAVE	A83	3	L	300	GOL		12/6	M	114	114	0	1	48
62	L	2	7	ME	FREDERICK	2/2	3	7	1B	AA		11/6	L	163	140	17	1	1B
63	L	2	7	P	SHEPHARD	E1	9	7	2B	AA		11/6	L	2198	534	20	2	1B
64	L	3	7	ME	ATTWOOD	3/5	1	7	2B	AA	I	11/6	L	966	966	0	2	1B
65	L	4	7	CCC	MCEWAN	EAT1	4	7	1B	SP	M	11/6	L	4091	4091	0	12	1B
66	L	2	7	ASC	COKE	B.1	1	7	1B	AA	R	11/6	L	270	240	18	1	1B

case of a parity or other machine failure the operator can quickly find the next job.

Each tape is logged by recording—using single letter characters when possible—in a tabular form the following information: Method of despatch: Size of Box: Department: Name and Identification number: Computing requirement: Output type and quantity required: Compiler: Priority (reruns, magnetic tape, industrial or X for jobs to be run only if Atlas has no other work available). Each job receives a transmission number (modulo 9999).

After transmission the tapes are returned to a set of pigeon holes. Each active user has a small pigeon hole, though sometimes it is necessary for two lesser users to share. Users leave their programs in the pigeon holes until the output arrives.

Output from the machine is received in large reels, and although attempts are made to separate the different data links at Manchester, the operators can recognize the identifying university code punched at the start of each output. Different outputs are separated by an easily recognized pattern of repeated upper and lower case characters. Because of the large amount of tape, it is not possible for the Nottingham operators to print it all up; only the logging information punched at the end of each is printed on a special roll of paper; this is cut, and the wound tape is Sellotaped to the log print. The second part of the tabulated log entry is now completed by recording: Reception date: How received: Computing time used: Time used for compiling: Store used: Number of blocks input: Number of block or lines output. By using suitable abbreviations, all this information is recorded in an 8 in. line—sample entries are given in **Table 4.** The output is then returned to the pigeon holes.

Equipment failures and other faults sometimes occur, and a report may be received from Manchester e.g. that tape No. 6863 had a parity or incorrect format error. The batching into sixes is a great help in tracing jobs, for if only five outputs are received the missing job may be known at once. As soon as a batch of output is cleared, missing programs are retrieved from the pigeon holes and carefully examined. If no fault is apparent, the job heading printup is marked R and returned to the

Table 5

Comments denoted by a tick

Vanishing program errors

Blank tape parity error
Other parity error
***A wrongly punched
JOB missing
OUTPUT O punched letter oh
O missing
Backspace in job heading
Escape code in job heading
Job heading error not listed above
***Z wrongly punched
Bad splice

Job heading comments

***A missing
7-hole output specified in lines
Line-printer output specified in blocks
Too much output
More than 6 characters in the identification number
Identification number not changed
Wrong layout in job heading title line

Tape preparation comments

No name and number written on tape
Not enough runout before job heading
Not enough runout at end
Too much runout in between
Tape wound backwards
Tape secured with Sellotape
Box secured with Sellotape
Box too large
Red corrections on job heading print
Hand alterations on job heading print
Please do not write on the box

Notes

Job not accepted
Job accepted because of unusual circumstances
The Computing Centre staff have corrected it for you.

tray for retransmission. If a user has removed his program prematurely from the pigeon holes, it is logged "not available" and forgotten. If a second rerun should be required (marked R^2 on the box) the tape is checked by running through a Flexowriter—often after link duplication to detect damaged tape—possibly acceptable to a Flexowriter—before transmitting a third time.

In order to reduce the incidence of incorrect format errors, all jobs are vetted in the Computing Centre before transmission. At first, time was wasted writing notes to erring programmers, so a "comments sheet" was introduced, **Table 5.** To maintain high standards, the Computing Centre refuses work that could lead to time-wasting practices. Jobs requesting too much output or computing time are also rejected unless special arrangements have been made.

The time-table of a good day follows:

9.00 a.m.–12 noon	Receive and log mail from Manchester and Chilton, a job fitted in where possible or given to a volunteer user.
9.30 a.m.–10.15 a.m.	Receive output from night runs (it usually takes until 9.30 a.m. to sort at Manchester).
10.15 a.m.–12.15 p.m.	Transmit programs.
1.30 p.m.–2.30 p.m.	Transmit more programs.
2.30 p.m.–3.45 p.m.	Run on Atlas, Nottingham operators clearing other work, e.g. preparing programs for mail to Chilton.
3.45 p.m.–4.45 p.m.	Receive output from Manchester.
4.45 p.m.–5.15 p.m.	Transmit reruns and any other programs possible; other work mailed.

On such a day, the two operators in the Computing Centre are very hard pressed, and passing users are called upon to help. Breakdowns in the normal computing service allow the staff time to prepare summary statistics and other information required, to check departmental accounts, and sometimes to punch programs for Computing Centre staff or external customers.

To keep users informed of the operational state of the system, flags are posted in the Computing Centre windows. A white flag with a red diagonal stripe indicates that output is now being received by link from Manchester; an upright blue cross indicates that Atlas or the return data link is unserviceable.

When the monthly accounts are received from Manchester, the Computing Centre pays and subsequently recovers the cost from the individual departments at Nottingham. Occasionally a job may be wrongly charged, for example it may have been run twice through restarting after an Atlas breakdown. Users are required to present suitable evidence of such errors in the Computing Centre, and if accepted a credit is allowed against subsequent accounts. This avoids long delays, which would throw an unnecessary financial burden on Manchester University or the Cripps Computing Centre.

Owing to the inadequate staff complement of the Cripps Computing Centre—a Director and one operator for the first year, plus an Assistant Lecturer and a second operator the second year—it was difficult to provide an adequate teaching and advisory service for the 150 users, so a "Computer Users Advisory Panel" was set up. Each department making extensive use of the computing facilities is required to nominate a potential expert programmer to take full responsibility for his department, including teaching, advice, and vetting programs to avoid waste of valuable machine time. As soon as this panel acquired skill, the Centre's workload was reduced to more tolerable proportions. Lectures on programming and the like are still provided by the Computing Centre—usually on a one-day "crash program" basis—but whenever possible members of the panel are brought in to help. One-day courses on such topics as elementary Atlas Autocode, advanced Atlas Autocode, machine code, elementary ALGOL and Advanced ALGOL are repeated as often as required. More conventional series courses are provided mainly by Advisory Panel members through their own departments.

At first, there was a serious shortage of Flexowriters. Night bookings were made for users requiring long typing sessions, and daytime use of Flexowriters was restricted to 15 minutes. The situation was aggravated by the high noise level of Flexowriters, as the machine used to print data-link output could not be operated while using telephones. However, a Flexowriter silencing hood was developed in the Department of Mechanical Engineering, with the necessary flaps for control of the machine, reducing the noise level by up to 10 db. Additional Flexowriters have been bought by many of the departments with sufficient workload, and the University now has thirteen plus one set of 5-hole equipment, in addition to several sets of experimental apparatus producing punched paper tape for direct input to Atlas; many departments also employ their own operators.

6. Future requirements

A medium-sized KDF 9 computer is to be installed at Nottingham at the end of this year. This is evidence not that the data link has failed, but rather that it has been successful in encouraging the development of computer-based teaching and research that would not otherwise have been possible. We would not be buying and maintaining a computer of our own if we could have obtained an equivalent computing capacity with the data link alone. In fact, the link is not being abandoned entirely; after being kept in operation for a few extra months to provide a service until work is transferred, one terminal will be moved from Manchester to provide the four departments in the School of Agriculture—11 miles distance from the main Nottingham campus—

with a direct link to the computer at Nottingham. If possible, occasional jobs may be exchanged with Manchester University by way of the public network.

Using the off-line data link has proved that most jobs can be performed using a remote computer. There seems no inherent reason that each centre should have a computer of its own. All that matters is that computers exist, and that it is possible to have computing done (Buckingham, 1965). But while the Nottingham data link could provide a small group of users with access to the facilities of a large and powerful machine, the time allocation available is far too small for a university. Quite apart from imposed input and output limitations, we need at least five times the present computing capacity; thereafter, the reasonable requirement could double every year if allowed to do so.

The demand for increased input/output facilities would not increase at such a pace. Input is naturally limited by human typing, and output by human reading, assuming of course that backing stores are available to record programs and other files required by the individual users of the machine. It would be useful if data links could operate at—say—one hundred times the present speed, in order to cope with data-processing applications—secretarial work and the like—not acceptable with the present system. Some of the work could be taken by local machines, but it might then prove desirable to have even faster data links to exploit the possible speeds of machine-machine communication.

It is quite certain, however, that it is not possible to fill adequately all the functions of a computing centre with the staff available at Nottingham, even with the active co-operation of experts at a parent centre such as Manchester. The intended functions of university computing centres are teaching with the associated advisory services, research in the computer sciences, and provision of a computing service (see Buckingham, 1965); the Nottingham staff have been struggling to achieve these three independent aims and financial viability as well. The Cripps Computing Centre has no formal teaching commitment at the present time, and independent research has been virtually abandoned. Part of the computing service requirements and teaching requirements have been covered by delegation to the different departments using the computer. There are some advantages in this arrangement; students of each subject are taught to program by experts in their own field, taking examples from the students' own experience —often in laboratory classes. But there seems a reasonable limit to the extent to which this can be done. Wealthy departments can buy equipment to provide more paper tape than the Computing Centre can handle, and their staff may enjoy sufficient leisure to outstrip the Computing Centre staff in software techniques and other specialized knowledge.

Financial success seems even harder to achieve with a university computing centre trying to maintain its other commitments. Certain costs can be recovered by charging users, but this in itself can lead to a serious increase in the administrative workload of the Centre; it could eventually prove necessary to charge for several hundred jobs a day. Many Nottingham service departments are financed in this way, but they tend to carry a smaller number of individual jobs. Alternatively, money can be obtained by selling computing services to outside customers, with additional charges to cover cost of programming effort. But it is difficult to start such work with a computing centre that is already saturated with other activities. Perhaps the solution might be some kind of nationalization of computing services, releasing universities for their primary teaching and research commitments?

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