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A METHOD OF BILLING THIRD GENERATION COMPUTER USERS

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Presented in this report is a method for charging users for the processing of their applications on third generation digital computer systems. For background purposes, problems and goals in billing on third generation systems are discussed. Detailed formulas are derived based on expected utilization and computer component cost. These formulas are then applied to a specific computer system (UNIVAC 1108).

The method, although possessing some weaknesses noted herein, is presented as a definite improvement over use of second generation billing methods.

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DEFINITION OF TERMS

CPU	Central processing unit
IO	Computer INPUT/OUTPUT of data or instructions by IO channels between memory and IO devices
Component	A computer subsystem or device such as a CPU or an IO channel
Program	A set of instructions and data processed on a computer for the purpose of determing specific results
CRU	Computer resource unit
STU	Space-time unit
Clock Time	Actual elapsed real time
Core	Main memory of computer for storage of data and instructions
K	1000
Mass Storage	Random access storage such as drums and disks
CCP$	Cost for N minutes of CPU time
CCW$	Cost for W words of core used for N CPU minutes
CCWI$	Cost for W words of core used for N IO minutes
CR1	CPU-core CRU
CR2	IO-core CRU
CR3	Mass storage CRU
CR4	Tape CRU
CR5	Unit record CRU
Unit Record	A unit of information processed by unit record devices such as line printers, card readers, and punches
Accounting	Statistics maintained by a computer concerning various component utilizations by each program

A METHOD OF BILLING THIRD GENERATION COMPUTER USERS

SUMMARY

Billing, or customer charging, on third generation computer systems becomes a complex effort if it is to be accomplished from a logical standpoint which is both fair to all customers and succeeds in recovering the cost of the computer system. A billing algorithm which appears to meet these requirements is presented herein.

The algorithm is based on the expected utilization of the various components of the computer system and the relative cost of those components. A common cost is derived for a unit of computation. Appropriate units of all components are then equated to this cost. Units of computation (computer resource units) can then be summed for all components and multiplied by the cost of a single unit of computation to obtain the actual cost or billing charge.

The algorithm has been applied to the MSFC UNIVAC 1108 multiprocessor system and was shown to be successful in recovering the cost of the system while at the same time charging the user for the specific facilities used.

INTRODUCTION

Billing on computer systems prior to third generation has been generally totally based on either central processing unit time or elapsed time. Since a single user was utilizing the system at a given time, this was an adequate method. However, on third generation computer systems there will usually be several user programs residing in different parts of memory at a given time and all will be sharing the use of the various system components such as central processor drums and input/output channels. It can easily be seen that second generation methods should not be used for billing the user on a third generation computer system. It becomes a rather complex effort to determine a means whereby the user can be charged fairly for the computation he performs and still insure that the sum of all user charges will cover the total computer system cost.

BILLING GOALS

In developing a billing algorithm the first question to arise is "What is billing to accomplish?" The goals which are felt to be most important are described below.

Cost Recovery

Of course the primary concern in billing is to recover whatever cost may be incurred in providing computing capability. Not everyone would attempt to recover the same type of cost associated with a computer system. If a system is rented then the rental cost may be the main item to be recovered. However, if a system is purchased then the cost of operation may become the prime item of recovery.

Cost Apportionment

By cost apportionment we mean the sharing of the total computer cost among the various users. This apportioning should be accomplished in an equitable manner. In order to do this we must, as far as possible, charge the user for the specific portions of the system which he utilizes. A common mistake is to charge the user based on CPU usage when the heaviest usage may really be, for instance, core and IO.

Repeatability

A computer system user should have some idea how much a run on the computer will cost. In order to have this information, billing charges must be repeatable for identical runs. This means if a run requiring exactly the same facility usage is run at two different times, the cost for the two runs should be the same.

Cost Analysis

One reason for having a billing algorithm, other than for recovering the cost of a system, is to provide a means of analyzing the importance of projects or programs in relation to their actual cost. If the goal of equitable cost apportionment is realized, then management will have at its disposal the true cost of various programs.

BASIS OF ALGORITHM

The billing algorithm involves a space-time relationship and is based on both utilization and relative cost of system components. Our aim is to find a unit of computation which we will call a computer resource unit (CRU). We will define a space-time unit (STU) for the various system components. An STU will be equal to a CRU for a specific component but since STU's are defined differently for different components, we cannot add STU's. However, it will be shown that CRU's are equal in cost and thus can be summed for all components.

Space-Time Relationship

The two basic quantities available for use in a computer system are space and time. If the central processing unit (CPU) executes an instruction, CPU time is involved along with core space and core time. Core space would be space occupied by a program and core time would be the time the core is actually in use; that is, the CPU is executing instructions in this case. If a magnetic tape is being read, then IO time is involved along with tape unit space. A tape unit is used here for space since the physical unit totally belongs to the program using it. In the case of random access storage (drums, for example) space involved would be only that number of words or characters assigned to a program.

Relative Component Cost

In the formulas on the following pages, it will be seen that an amount of space-time capacity for each component is determined for a common cost (Y$). Therefore, the charge for use of each component will be weighted by its cost relative to the cost of other components. These costs used could be the rental cost or possibly the purchase cost of the system. This does not mean that this cost is necessarily the cost to be recovered through billing. All this does is establish the relative value of components. If we wish to recover a different sum of money than that used in deriving our STU's, all we need to do is use a different figure for Y$ when we apply the billing charge.

Utilization

If we are to recover the cost of a system and not recover a sum much greater than the cost, then our billing algorithm must be based on utilization of the system. Since a component is only going to be paid for by those who use it, then the more it is used the less will be the cost per unit of time. There are three areas involved in utilization. These are total clock time, percentage of space, and percentage of time. Total clock time could be defined as the number of hours per month the system is in production. Percentage of space refers to the percent of a component's total space which is in active use, on the average, at any given time. Percentage of time refers to the percent of available accessing time of a component which is being used on the average. It should be pointed out at this point that, based on this algorithm, a program is charged only when it is making active use of some part of the system. By active use we mean the program must either be executing instructions on a CPU or performing IO. There is no charge if the program is in an inactive state even though facilities are being occupied.

CRU FORMULAS

Compute cost per N minutes (CCP\$) for CPU time.

$$\text{CCP\$} = \frac{\text{P\$} \times \text{N}}{\text{T} \times \text{SP1}} \quad , \tag{1}$$

where

P\$ = CPU cost per month
T = minutes of clock time per month
SP1 = percent of utilization of CPU .

Compute cost per N minutes (CCW\$) for W words of core used by CPU.

$$\text{CCW\$} = \frac{\text{C\$} \times \text{W} \times \text{N} \times 0.5}{\text{T} \times \text{SP2} \times \text{TW}} \quad , \tag{2}$$

where

C\$ = cost per month for all of core
T = minutes of clock time per month
SP2 = percent of utilization of total core by CPU
TW = total words of core .

SP2 is a composite of space percentage multiplied by time percentage; 0.5 is used to allocate half of core cost recovery to CPU. Now a CPU-core space-time unit can be defined as follows:

Cost of W (words of core) X N (minutes of CPU) = CCP\$ + CCW\$;

let

$$\text{CCP\$} + \text{CCW\$} = \text{Y\$} \quad , \tag{3}$$

then

Cost of W (words of core) X N (minutes of CPU) = Y\$.

Having found a value (Y\$) as the cost of a CPU-core space-time unit, we can now compute other component's STU's to equal Y\$. For IO core we first compute the cost of W words of core used for N minutes of IO (CCWI\$).

$$CCWI\$ = \frac{C\$ \times W \times N \times 0.5}{T \times SP3 \times TW} \quad , \qquad (4)$$

where

SP3 = percent of utilization of total core by IO.

Other quantities are as defined previously. SP3 is a composite of space percentage multiplied by time percentage; 0.5 is used to allocate half of core cost recovery to IO.

Time percentage in SP2 and SP3 is really percentage of CPU and IO boundness respectively. Space percentage is the same in both cases. Either IO or CPU is responsible for the core being in active use.

Now we can set up a ratio to determine the amount of IO core (WI) available for Y$.

$$\frac{WI}{Y\$} = \frac{W}{CCWI\$}$$

$$WI = \frac{W \times Y\$}{CCWI\$} \quad . \qquad (5)$$

An IO-core STU is then

WI (words of core) X (N minutes of IO)

Cost of IO-core STU = Y$.

A mass storage STU would be computed as follows. Let CD$ equal the cost of PS positions of mass storage used for N minutes of mass storage IO.

$$CD\$ = \frac{D\$ \times N \times PS}{T \times SP4 \times TPS} \quad , \qquad (6)$$

where

D$ = total mass storage cost per month
TPS = total mass storage positions
SP4 = percent utilization of mass storage .

SP4 is a composite of space percentage multiplied by time percentage. In order to determine the number of mass storage positions (DP) available for Y$, our ratio becomes

$$\frac{DP}{Y\$} = \frac{PS}{CD\$}$$

$$DP = \frac{PS \times Y\$}{CD\$} \quad . \tag{7}$$

A mass storage STU is then

DP (mass storage positions) X N(minutes mass storage IO)

Cost of mass storage STU = Y$.

Space-time units for other components can be computed in the same manner as above.

Having obtained our STU's we are now able to use actual accounting data to compute CRU's for the different facilities of a system.

CPU-Core CRU

Let

CRA	=	CPU-core CRU
CCS	=	CPU-core space for program
CPUT	=	CPU time for program
CCST	=	CPU-core space-time unit
IT	=	IO time for program
COR	=	total core space for program ,

then

$$CCS = \left(\frac{CPUT}{IT + CPUT}\right) \times COR \quad . \tag{8}$$

Since IO/CPU boundness was used in the separation of core between CPU and IO in the definition of STU's, it is used here in the actual CRU computation.

$$CRA = \frac{CCS \times CPUT}{CCST} \quad . \tag{9}$$

Since the CPU-core CRU involves two distinct costs (core and CPU), we must weight CRA accordingly if the resulting billing charge is to be meaningful.

$$CR1 = \left[\left(\frac{CCW\$}{Y\$}\right) \times \frac{CCS}{W \times N} + \left(\frac{CCP\$}{Y\$}\right)\frac{1}{N}\right] \times CPUT \quad .$$

If we let

$$A1 = \frac{CCW\$}{Y\$} \quad \text{and} \quad A2 = \frac{CCP\$}{Y\$} \quad ,$$

then

$$CR1 = \left[\frac{A1 \times CCS}{W} + A2\right] \times \frac{CPUT}{N} \quad , \tag{10}$$

where

CR1 = weighted CPU-core CRU .

<u>IO-Core CRU</u>

Let

CR2 = IO-core CRU
ICS = IO-core space for program
ICST = IO-core space-time unit ,

then

$$ICS = \left(\frac{IT}{IT + CPUT}\right) COR \tag{11}$$

and

$$CR2 = \frac{ICS \times IT}{ICST} \quad . \tag{12}$$

<u>Mass Storage CRU</u>

Let

CR3 = mass storage CRU
MSS = mass storage space for program
MST = mass storage IO time for program
MSST = mass storage space-time unit ,

then

$$CR3 = \frac{MSS \times MST}{MSST} \quad . \tag{13}$$

Tape CRU

Let

CR4 = tape CRU
TU = tape units for program
TT = tape IO time for program
TST = tape space-time unit ,

then

$$CR4 = \frac{TU \times TT}{TST} \quad . \qquad (14)$$

Unit Record CRU

Let

CR5 = unit record CRU
URS = unit records processed for program
URST = unit record space-time unit ,

then

$$CR5 = \frac{URS}{URST} \quad . \qquad (15)$$

In the case of unit record CRU's the space-time factor is included in the number of records processed. Accounting generally provides the number of records rather than time.

USES OF CRU's

The primary purpose of the CRU is in billing the customer. However, there are some other valuable uses. First, CRU formulas can be applied to a system to determine its actual capacity within a particular workload environment. We can compute the expected number of CRU's. For instance, we could take our total mass storage space, multiply by our total mass storage IO time for a month, and divide by the mass storage space-time unit. This would give us our expected mass storage CRU's for a month. If our utilization predictions used in defining STU's are correct for a particular month, then the actual CRU's will be very near the expected. Secondly, CRU's can be used in estimating computer usage. Instead of estimating only CPU time, users can arrive at CRU estimates for various facilities to be used. Thus, a much better workload projection can be realized to match with a system's capacity. Third, CRU's can be used to give a rough estimate of the throughput of a system being experienced at particular periods of time. Finally, CRU's can be used in comparing throughput capabilities of different systems for handling a particular type of workload.

APPLICATION OF CRU BILLING

In this section we will discuss gathering of information required for CRU billing, an actual application of the algorithm and problems associated with it.

Information Required

In determining CRU formulas for a specific system the following information will be needed:

1. Cost of system by components.

2. Utilization statistics by components or subsystems.

By far, the most difficult information to obtain would be the utilization statistics. These should cover a long period of time and might be obtained or estimated from accounting data or through use of hardware or software monitors.

After determination of CRU formulas, the following information will be required in applying these to obtain billing charges:

1. Cost to be recovered.

2. Accounting data containing space and time usage for programs by components.

It is not necessary that the cost to be recovered be the same as the system cost used in deriving the space-time units. The STU's will remain the same even if the total cost is different. All that is necessary is that a new value of Y\$ be computed.

Let

Y1\$ = new cost of STU
R\$ = new total cost to recover
S\$ = total system cost used in computing STU's ,

then

$$\frac{Y1\$}{Y\$} = \frac{R\$}{S\$} \tag{16}$$

and

$$Y1\$ = \frac{R\$ \times Y\$}{S\$} \quad . \tag{17}$$

Application of Algorithm at MSFC

This billing algorithm has been applied to both the 1108 3 X 2 and 1108 1 X 0 systems at MSFC. Production use of the CRU method of billing began on July 1, 1973, for both systems. This was done after several months of parallel running during which computer users were provided with comparisons of resulting charges between the new method of billing and the then current method (charge for CPU time only).

In implementing the CRU method, it was decided that since both MSFC 1108 systems are purchased Government systems, the cost to be recovered would be limited to the following:

1. Maintenance costs for 1108 hardware.

2. Cost of supplies such as paper, cards and tape.

3. Labor costs.

Current budget projections are used to determine the cost to be recovered. The relative value of the various computer components or subsystems is established by determining the actual operating costs associated with each. The operating cost for a subsystem includes the maintenance costs for that subsystem, the cost of supplies utilized by that subsystem, and the cost of labor required in utilizing that subsystem. As an example, the operating cost of a magnetic tape subsystem would include, in addition to maintenance cost, the cost of tapes, the labor cost of operators required for mounting tapes, and the labor cost of tape librarians required for administering the tape library and retrieving the tapes as necessary.

These costs were apportioned among the various CRU defined components of each system. (The CRU formulas and thus cost recovery are applied separately to the two systems.) Application of these formulas to the 3 X 2 system are shown in the following. Data used in the formulas can be found in Tables 1, 2, and 3. Table 1 shows utilization percentages for hardware components of the system. Table 2 shows the above costs apportioned among the hardware components. Table 3 shows 1108 3 X 2 capacities. The system generally is in production approximately 600 hours per month or 36 000 minutes of clock time.

In applying CRU formulas we chose 1 minute of CPU time with 16K words of core for the basic CPU-core space-time unit. Therefore using formulas (1), (2), and (3) we have

$$\text{CCP\$} = \frac{\$6936.67 \times 1}{36\,000 \times 0.3082} = \$0.62519558$$

$$CCW\$ = \frac{\$2870 \times 16(K) \times 1 \times 0.5}{36\,000 \times 0.13907 \times 262(K)} = \$0.017503892$$

$$Y\$ = \$0.62519558 + \$0.017503892 = \$0.642699472 \quad .$$

Compute IO-core STU's using formulas (4) and (5).

$$CCWI\$ = \frac{\$2870 \times 16(K) \times 0.5}{36\,000 \times 0.1192 \times 262(K)} = \$0.020421697$$

$$WI = \frac{16(K) \times \$0.642699472}{\$0.020421697} \cong 503K$$

$$\text{IO-core STU} = 503\text{K words of core} \times 1 \text{ minute of IO} \quad .$$

Compute FASTRAND STU using formulas (6) and (7).

$$CD\$ = \frac{\$8033 \times 1 \text{ minute} \times 1 \text{ POS}}{36\,000 \times 0.0753 \times 1920} = \$0.001543402$$

$$DP = \frac{0.6427 \times 1 \text{ POS}}{0.001543402} \cong 416 \text{ POS}$$

$$\text{FASTRAND STU} \cong 416 \text{ POS} \times 1 \text{ minute FASTRAND IO} \quad .$$

Using Tables 1, 2, and 3, calculations of other space-time units can be made. The results are as follows:

432 STU	≅	0.7 POS × 1 minute 432 IO
1782 STU	≅	18.0 POS × 1 minute 1782 IO
Tape STU	≅	0.8 units × 1 minute tape IO
Unit Record STU	≅	1188.0 records (lines and/or cards) × 1 minute unit record IO .

It should be noted that the values in Table 2 are projected costs subject to change but are used here to illustrate application of the method.

The total cost to be recovered is \$1 851 115 for 1 year, according to the projection. Only \$1 560 468 of this cost can be logically apportioned among the various components. In order to recover the larger cost we must adjust Y\$ by applying formula (17).

Therefore

$$Y1\$ = \frac{\$1\,851\,115 \times \$0.6427}{\$1\,560\,468} = \$0.76 \quad .$$

Although the cost of disks is included in the above total, no computation of disk CRU's is made of course and the disk cost will only be recovered when that cost is incurred.

When a run is made on the 1108, CRU's are computed based on the resources used by that run. The CRU's are then summed and multiplied by $0.76. Thus each CRU generated by a run costs $0.76. The 1108 operating system has been modified so that at the end of the print file associated with a run, a summary of all CRU's generated by that run is printed along with the resulting total cost.

Problems

There are some problems associated with the CRU billing system. The first is that system utilization is not always predictable and when utilization percentages change, then CRU formulas must be adjusted. However, if utilization percentages, when taken over a long period of time (6 months for example), are fairly stable then there should be an infrequent requirement for adjustment. Secondly, it is possible that utilization of already lowly utilized components could be discouraged since relatively higher charges would result.

Adjustment of CRU Formulas

Once CRU formulas have been established which recover an amount within a small range of the actual cost (±10 percent is considered acceptable for any one month but the deviation should be much less over a period of several months, possibly ±3 percent), then adjustments will be necessary as mentioned above due to changes in utilization percentages.

In originally defining CRU formulas various data from accounting reports, operating system throughput measurement routines, etc., were utilized to determine the expected utilization of each hardware component. Now that CRU formulas have been defined and are in use, the CRU statistics themselves can be used to determine utilization percentages and thus adjustments required in the CRU formulas. The only exception being that CPU utilization must be obtained from accounting reports.

Knowing the capacity of 1108 hardware and knowing utilization percentages used in the CRU formulas, we can compute expected CRU's per hour for each CRU defined component. As indicated earlier, if the utilization percentages are correct, then the actual CRU's per hour will be equal to the expected CRU's per hour.

As an example we can compute expected CPU-core CRU's per hour (EC) by inserting the proper data in formula (10)

$$EC = \left[\frac{A1}{16} \times 262 \times SP2 + A2 \times SP1 \times 3 \right] \times 60 \quad .$$

The total CPU-core capacity on the 3 X 2 1108 is 262K words of core and 3 CPU's. At present the expected total CRU's per hour on the 3 X 2 system equals approximately 276.

An adjustment of utilization percentages is not required at this time; however, if one were needed the following steps would be taken.

1. Find the user CPU utilization percentage by examining accounting reports.

2. Compute a new Y$ using the CPU percentage found in step 1.

3. Compute the expected CPU-core CRU's per hour (EC) using a new Y$ and new CPU percentage.

4. Compute actual CPU-core CRU's per hour (AC).

5. Compute deviation (D) = EC - AC. This deviation is due only to a change in core utilization by the CPU.

6. Compute percent deviation (P) = D/EC. If P is negative, then CRU generation is high and therefore the percentage (SP2) for core utilization by CPU must be raised in order to lower cost recovery. If P is positive, the utilization percentage must be lowered. Therefore the new utilization percentage ($SP2_N$) = SP2 - P X SP2.

7. Compute new utilization percentages for all components which require adjustment by making adjustments based on the deviation of actual from expected as described in step 6 for core utilization by CPU.

8. Compute new STU's using new Y$ (if computed) and new utilization percentages.

If CPU-core utilization has not deviated appreciably from the expected, only steps 7 and 8 are necessary.

CONCLUSIONS

There appears to be no perfect solution to billing on third generation computer systems. Although there are some known weaknesses in the billing algorithm described herein, it is felt that this algorithm does offer a feasible solution to the billing problem. At the very least this algorithm is a good starting point for billing on third generation systems and appears to be a definite improvement over use of second generation methods.

TABLE 1. MSFC 1108 (3 X 2) UTILIZATION PERCENTAGES (USER USAGE)

	Percent
CPU	30.82
Core (Used by CPU)	13.907*
Core (Used by IO)	11.92 *
FASTRAND	7.53
1782	3.02
432	0.7
Tapes	2.08
Unit Record	12.49

* Total active core utilization equals 13.907 percent plus 11.92 percent or 25.827 percent. Most of the remaining 74.173 percent of unused core is due not to the core being unoccupied but to the core being inactive; i.e., runs presently occupying core are not utilizing the CPU or performing IO. Actual core occupancy is generally about 80 percent.

TABLE 2. MSFC 1108 MONTHLY COSTS

	Labor	Supplies	Maintenance	Total
CPU	$11 470		$ 9 340	$20 810**
Core			$ 2 870	$ 2 870
FASTRAND	$ 1 401		$ 6 632	$ 8 033
1782			$ 4 287	$ 4 287
432			$ 1 628	$ 1 628
Tapes	$13 055	$2 000	$ 4 885	$19 940
Unit Record	$25 178	$9 035	$14 925	$49 138
Disk			$23 333*	$23 333
Subtotal				$130 039
Unallocated Cost				$ 24 220.58
Total				$154 259.58

* Disks are to be added in FY 74. The cost in this case includes lease charges.

** Total cost for 1 CPU is one third of $20 810 or $6 936.67.

TABLE 3. MSFC 1108 CAPACITIES*

Core	262K words
FASTRAND	1920 positions
1782	109.7 positions
432	6.84 positions
Tapes	32 units (drives)
Unit Record	20 200 lines and cards per minute
CPU	3 minutes per minute of clock time

* Disk capacity has not been included since these have not been installed and thus CRU's are not presently computed.

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