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A DEDICATED MINICOMPUTER SYSTEM FOR INFORMATION MANAGEMENT IN A NEONATAL INTENSIVE CARE UNIT

William W. Frayer

INTRODUCTION

Digital computers have many potential applications in the neonatal intensive care unit (NICU), facilitating both patient management and administrative operations. Applications in critical care units can include patient monitoring, data distribution, intake and output balances, nutritional analysis, drug calculations, charting of laboratory data, nursing notes, and discharge summaries.

One approach to critical care computing that has been investigated over the past 15 years is the use of dedicated minicomputer systems to capture, process, display, and report data. This approach has proved particularly difficult to implement; consequently, there are few examples of functional systems now in routine use. Poor user acceptance and an unfavorable cost-benefit ratio have been at the root of this problem in the past.

Despite previous failures, however, investigation of this approach has continued because it offers substantial advantages over alternative methods. The relatively low price of computer memory and mass storage devices, as well as increased sophistication of operation systems, have led to increased user acceptance and cost-effective operation. The principal advantage of the minicomputer system is that with a properly conceived data capture process, a comprehensive, accurate data base can be compiled for all patients in real

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This chapter describes the development and operation of a bedside real-time patient data management system in the Perinatology Center at the New York Hospital-Cornell Medical Center, which has been in operation since 1976.[1] Special emphasis is placed on how we approached the problems of user acceptance and optimal use.

SYSTEM DESCRIPTION

With the opening of a new NICU as the initial facility of the Perinatology Center in 1976, total bed capacity doubled from 25 to 50 beds. Fifty neonatal intensive care patients represent a lot of information. In some patients, this means more than 500 new laboratory values daily. To keep these data organized would be a big job. The burden of assembling and interpreting data on this number of patients suggested a clinical need for an effective computerized information system. What better way than to put all these data into a computer and give the users direct access via bedside terminals.

The design of the new NICU had included a computerized information system to gather monitored and observed vital sign data, nursing measurements of intake and output, ventilation parameters, as well as all stat laboratory values. Only commercially available systems were considered. The possibility of developing a system "from scratch" represented a commitment of a great deal of time, having to cope with innumerable difficulties in launching such a project, as well as the expense of providing hardware and of developing supporting software. At that time, no manufacturer offered a totally suitable commercial system for sale. However, the Hewlett-Packard 5600A patient data management system did appear to offer a number of advantages for NICU users. The most important of these, perhaps, was the simplified bedside terminal with separate CRT screen and 16-key, hand-held keyboard (Fig. 22.1). Also, since the system was programmed in FORTRAN, it represented an ideal candidate for modification and adaptation to meet our needs.

Some custom programming was included in our order to permit problem-oriented data retrieval, the generation of special format reports, and the use of optical mark reader cards for data entry. The hospital purchased the system with these software modifications and hired a programmer to continue to develop and tailor the system for smoother operation. In addition, a second, smaller system was purchased to permit the off-line development and testing of new and improved programs. All equipment in the system was covered by service contracts available from the manufacturer.

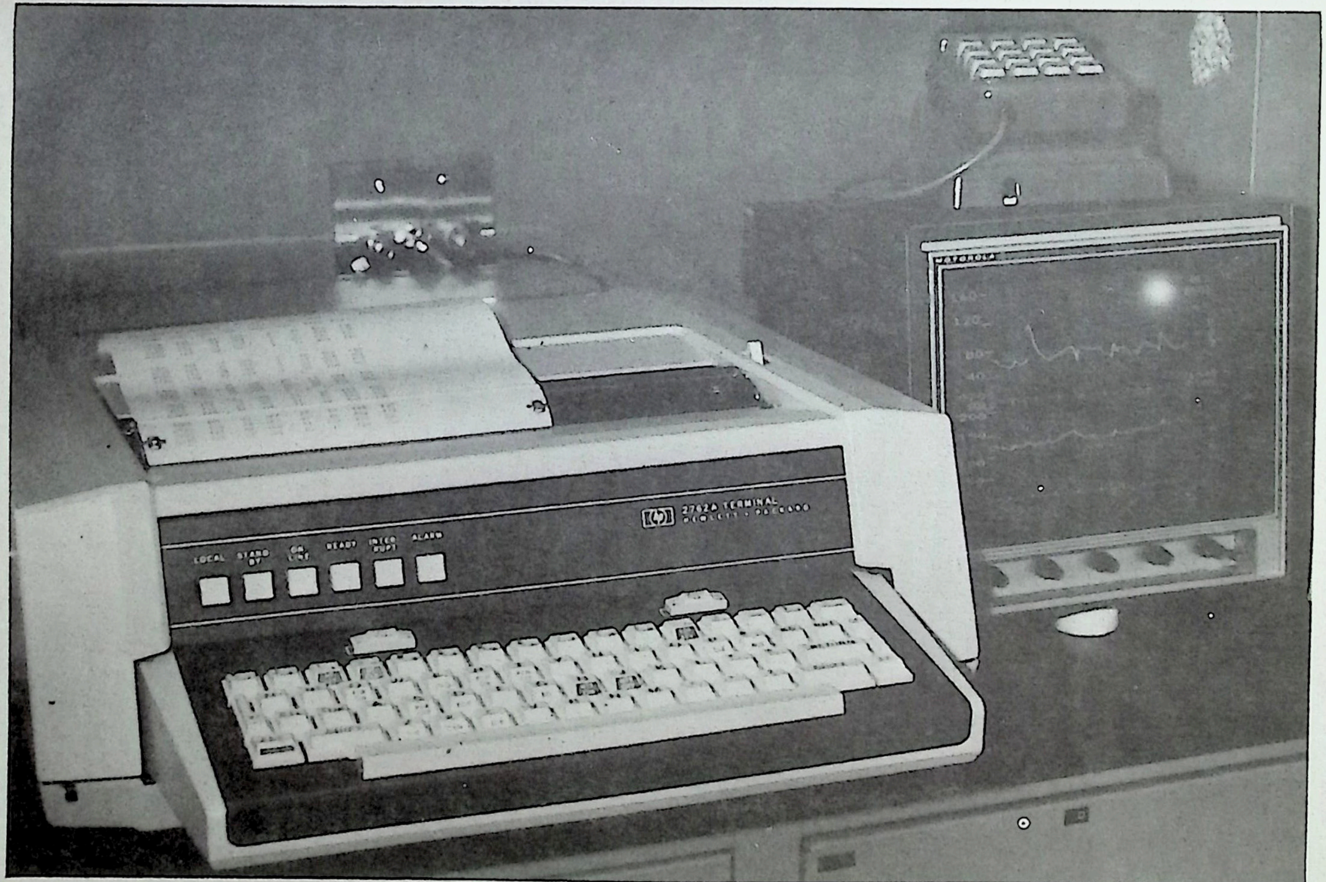


FIGURE 22.1. Bedside graphics CRT terminal (middle right), hand-held 16-key keyboard (upper right, on top of CRT terminal), and printer (lower left). Both the printer keyboard and the hand-held portable keyboard may be used to activate the system for purposes of data input or data retrieval.

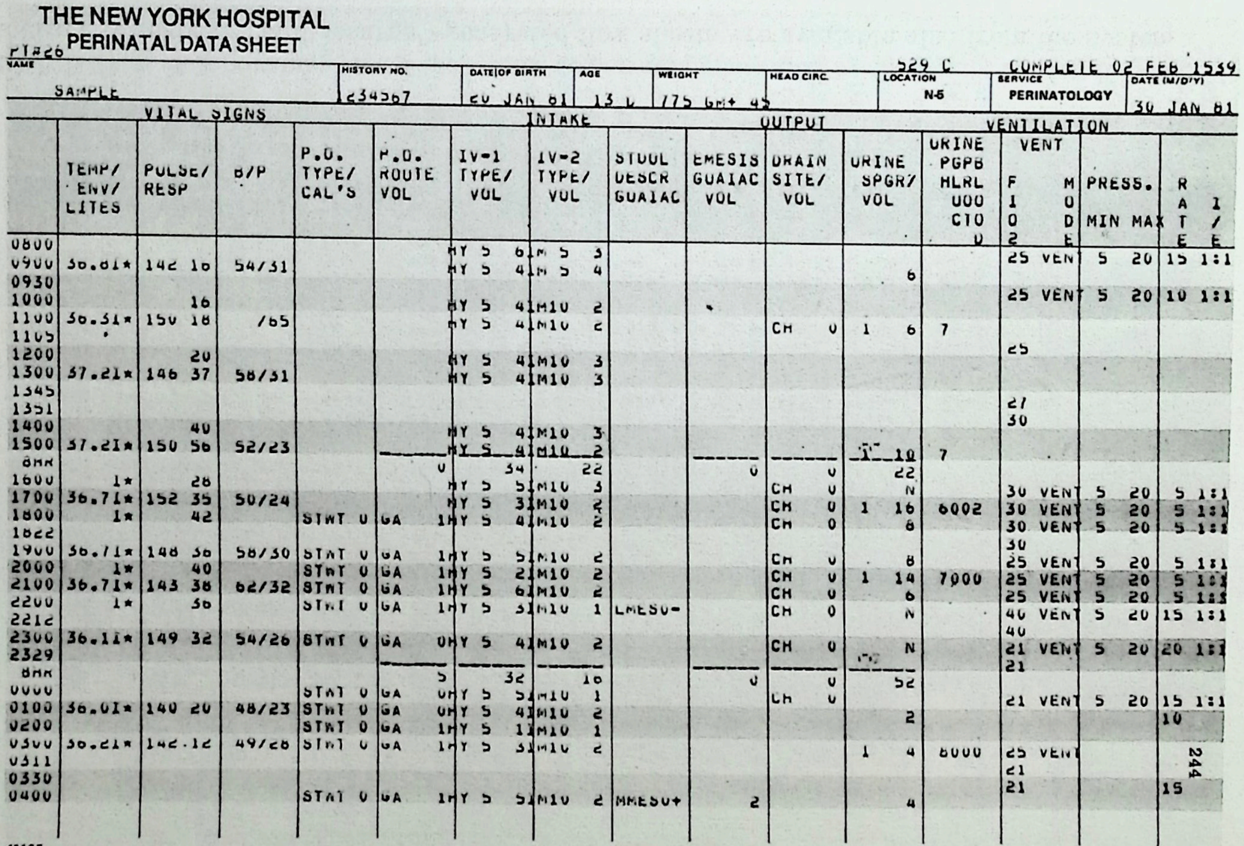
The anticipated functions of the system were to include storage, retrieval, and charting of vital signs, intake and output, ventilator parameter change, and critical laboratory data. Chart documents of selected and reformatted data would be legibly printed by the computer at preset time intervals. This had to be one of the most straightforward clinical computing tasks possible: to record data and play it back. Once we had mastered that, we could begin to reap the other benefits of a computerized medical data system, including the following:

Automatically accumulate long-term data bases of our clinical experience, as a source for clinical research projects and quality assurance review
Begin signal processing, waveform analysis, and diagnostic computing
Allow for on-line pulmonary function testing
Computerize chart notes
Automatically print out discharge summaries

Hardware

Since user access to computers has been one of the most important factors influencing their acceptance by medical personnel, particular attention was paid to the hardware arrangements that would be available at the bedside. We wanted the nurses caring for the most critically ill infants to be able to enter data easily and to review all laboratory data pertaining to their patients at will. Fifteen NICU beds have CRT screens and hand-held keyboards located next to them, along with the vital sign monitors and other bedside equipment. Intermediate care areas for infants not as critically ill have a terminal in each eight-bed room. The special care nursery, which generates even fewer data, has one terminal for 10 beds. Additional terminals are located in the nursing and neonatology offices, at the clerk's desk, in the laboratory, and in the conference room. In all, more than 30 data access points are available.

Two printers handle hard-copy output destined for the patients' charts or for various administrative uses. (See also Figs. 22.1-22.3.) All data entered are simultaneously logged both in the disk file and in a magnetic type transaction log. The central processor for the system is a 128-kilobyte (KB), 16-bit-word minicomputer (Hewlett-Packard 21 MX-M). The second system, for program development and testing, has an identical central processor unit CPU and mass storage capability and has been used as a source of "spare parts" in cases of failure of the primary equipment. Annual total down time averages less than 24 hours.



THE NEW YORK HOSPITAL
PERINATAL DATA SHEET

PT#26

NAME	HISTORY NO.	DATE OF BIRTH	AGE	WEIGHT	HEAD CIRC.	LOCATION	SERVICE	DATE (M/D/Y)
SAMPLE	1234567	20 JAN 81	13 D	775 GM+ 45		529 C N-5	COMPLETE 02 FEB 1539 PERINATOLOGY	30 JAN 81

	VITAL SIGNS			INTAKE				OUTPUT					VENTILATION		
	TEMP/ ENV/ LITES	PULSE/ RESP	B/P	P.O. TYPE/ CAL'S	P.O. ROUTE VOL	IV-1 TYPE/ VOL	IV-2 TYPE/ VOL	STOOL DESCR GUAIAC	EMESIS GUAIAC VOL	DRAIN SITE/ VOL	URINE SPGR/ VOL	URINE PGPB HLRL UOO CTO D	VENT FIO2 MODE	PRESS. MIN MAX	RATE I/E
0800						HY 5 6	M 5 3								
0900	36.81*	142 16	54/31			HY 5 4	M 5 4				6		25 VENT	5 20	15 1:1
0930															
1000		16				HY 5 4	M10 2						25 VENT	5 20	10 1:1
1100	36.51*	150 18	/65			HY 5 4	M10 2			CH 0	1 6	7			
1105															
1200		20				HY 5 4	M10 3						25		
1300	37.21*	146 37	58/31			HY 5 4	M10 3								
1345															
1351													27		
1400		40				HY 5 4	M10 3						30		
1500	37.21*	150 56	52/23			HY 5 4	M10 2				1 10	7			
8HR					0	34	22		0	0	22				
1600	1*	28				HY 5 5	M10 3			CH 0	N				
1700	36.71*	152 35	50/24			HY 5 3	M10 2			CH 0	1 16	6002	30 VENT	5 20	5 1:1
1800	1*	42		STWT 0	GA 1	HY 5 4	M10 2			CH 0	8		30 VENT	5 20	5 1:1
1822													30 VENT	5 20	5 1:1
1900	36.71*	148 36	58/30	STAT 0	GA 1	HY 5 5	M10 2			CH 0	8		30		
2000	1*	40		STWT 0	GA 1	HY 5 2	M10 2			CH 0	1 14	7000	25 VENT	5 20	5 1:1
2100	36.71*	143 38	62/32	STWT 0	GA 1	HY 5 6	M10 2			CH 0	6		25 VENT	5 20	5 1:1
2200	1*	36		STWT 0	GA 1	HY 5 3	M10 1	LMESO-		CH 0	N		25 VENT	5 20	5 1:1
2212													40 VENT	5 20	15 1:1
2300	36.11*	149 32	54/26	STWT 0	GA 0	HY 5 4	M10 2			CH 0	N		40		
2329													21 VENT	5 20	20 1:1
8HR					5	32	16		0	0	52		21		
0000				STAT 0	GA 0	HY 5 5	M10 1			CH 0					
0100	36.01*	140 20	48/23	STWT 0	GA 0	HY 5 4	M10 2				2		21 VENT	5 20	15 1:1
0200				STWT 0	GA 1	HY 5 1	M10 1								10
0300	36.21*	142 12	49/28	STWT 0	GA 1	HY 5 3	M10 2				1 4	6000			
0311													25 VENT		
0330													21		
0400				STAT 0	GA 1	HY 5 5	M10 2	MMESO+	2		4		21		15

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FIGURE 22.2. A 24-hour vital sign, intake/output, and ventilatory parameter flow sheet generated by the computer for inclusion in the patient's chart.

THE NEW YORK HOSPITAL
PERINATAL DATA SHEET

PT#26 | 529 C | LAB SUMM 02 FEB 1528

NAME	HISTORY NO.	DATE OF BIRTH	AGE	WEIGHT	HEAD CIRC	LOCATION	SERVICE	DATE (M/D/Y)
SAMPLE	234567	20 JAN 81	13 D	775 GM+ 45		N-6	PERINATOLOGY	18 JAN 81

		GASES						ELECTROLYTES							
TIME	DATE	PH	PCO2	PO2	FIO2	TOTAL BILI	HCT	NA	K	CL	CO2	BUN	CA	GLUC	OSM
1526	20 JAN	7.350	31.	92.0	40.										
1547	20 JAN						39.0								
1740	20 JAN	7.370	21.	87.0	55.										
1914	20 JAN	7.380	23.	131.0	55.			134.	3.8	108.	16.0	3.	7.6		
2050	20 JAN													89.	
2119	20 JAN	7.370	22.	110.0	50.										
0000	21 JAN				50.										
0058	21 JAN	7.360	32.	45.0	45.										
0306	21 JAN	7.340	35.	39.0	50.										
0550	21 JAN	7.280	42.	60.0	70.	5.4	45.0	139.	5.7	115.	13.0	9.	6.8	67.	
0659	21 JAN	7.280	44.	65.0	65.										
0800	21 JAN				60.										
1030	21 JAN				55.										
1033	21 JAN	7.340	34.	79.0	60.			141.	6.3	117.	18.0	14.	7.1	112.	
1055	21 JAN													91.	
1254	21 JAN	7.350	31.	78.0	55.										
1300	21 JAN				50.										
1606	21 JAN	7.310	35.	75.0	50.	6.0	47.0								
[illegible]31	21 JAN	7.280	33.	59.0	45.										
[illegible]00	21 JAN	7.420	24.	56.0				136.	5.9	106.	19.0	21.	8.3		
2026	21 JAN													268.	
0000	22 JAN				45.										
[illegible]47	22 JAN	7.350	37.	67.0	45.										
0200	22 JAN				40.										
0359	22 JAN	7.300	41.	42.0	40.										
0400	22 JAN				45.										
0540	22 JAN	7.350	34.	62.0	45.	6.3	40.0	135.	6.2	108.	15.0	27.	8.4	207.	
0700	22 JAN				45.										
0923	22 JAN	7.420	33.	70.0	45.										
1056	22 JAN													174.	
[illegible]	22 JAN	7.390	26.	58.0	40.										
[illegible]	22 JAN	7.370	29.	57.0	40.	6.3	41.0	138.	6.9	107.	18.0	33.	7.8		
1400	22 JAN				40.										
1738	22 JAN	7.330	27.	54.0	40.										
1906	22 JAN	7.330	32.	59.0	40.	6.3	38.0	136.	6.2	102.	17.0	33.	7.7		
2012	22 JAN													86.	

FIGURE 22.3. A laboratory flow sheet (time sequenced) generated by the computer for inclusion in the patient's chart. Weekly or "at discharge"-generated flow sheets are available also from the system.

Data Entry

Data collection begins when a patient is admitted to the NICU, identified for the computer system, and assigned to a bed. A unit clerk enters names, addresses, and phone numbers of parents, referring physicians, and hospitals, as well as data concerning the pregnancy and delivery. Throughout the hospital stay all vital sign observations, intake/output, and ventilation data and most laboratory values are entered into the system. Responsibility for entering data is assigned to the person making the observation.

Entry is usually by keyboard—either at the bedside or directly from the laboratory. All bedside data entry was originally accomplished using a pencil on optical mark reader cards so that they could be reread if data were lost or files became damaged. Cards offered the advantage of being usable without access to a terminal and permitted the recording of computer-readable data even when the system was not operational. Although cards worked surprisingly well, entry errors occurred, and data were frequently missing. It became common practice among nurses to delay the irksome task of filling out cards until the end of the shift. This delay of up to 8 hours of data entry made the use of the system by other caretakers less helpful. In addition, if a systematic mistake had been made in card marking, it was possible to lose a whole 8-hour block of data and not have the person responsible for recording it available for corrections. For these and other reasons (see below), we eventually went to all direct entry, using the hand-held keyboards at the bedside. Laboratory data had been entered from the outset, using a terminal located in the laboratory. Data from the bedside monitors is read into the computer directly, but it has never been used to replace nursing vital sign observations.

Data Retrieval

Information is retrieved primarily at CRT terminals. Displays are organized according to individual medical problem lists and can include tabular or graphic presentations of raw data or analyses of fluid and electrolyte balance or nutritional intake. By selecting the problem for review, retrieval is initiated on all relevant data in the system. Data is presented in a sequence of graphic or tabular displays. Initially, only raw data could be retrieved. Data automatically recorded from the bedside vital sign monitors can be listed or plotted as well, but these values are never entered into the chart record unless they have been verified by a human observer.

Vital sign, intake/output, and ventilator parameter flow sheets are printed for the chart on a daily basis (Fig. 22.2). Sequential laboratory value flow sheets are printed as often as needed, depending on the frequency of blood sampling (Fig. 22.3), or are charted weekly and reprinted at discharge.

DEVELOPMENT AND OPERATING CONSIDERATIONS

Our objective in the development of this information system has been to make patient data easily available to caretakers and to eliminate unnecessary clerical tasks associated with this information. Success is gauged by evidence of user acceptance as indicated by record completeness for data entry and amount of use by physicians for retrieval.

In looking back over the first 5 years of our experience, I am impressed by how difficult it has been to live up to the expectations of our medical and nursing users. Doctors and nurses are necessarily the direct users of this type of system. Neither group can generally be expected to be particularly interested in computer systems. Consequently, the level of impatience with either slow response or system malfunction has proved very high in our experience.

A second observation concerns the vulnerability of this type of system—not vulnerability to malfunction, but vulnerability to poor cooperation. Completeness of data has proved essential for the system to be clinically acceptable. If users generally believe that the computer's data base might be incomplete, no matter how elegant the retrieval or applications programs are, the data will seldom be used. If data are not used, personnel feel less compelled to continue to use them, and a vicious circle is set in motion.

A final observation is that our information system has been perceived as being especially useful to the clinicians only when it has offered information that is not readily available from other sources or in other ways. Personnel have seemed unlikely to turn to the computer for those tasks they believe they can perform equally well.

We have used most of our programming resources over the past 5 years to improve the basic problems that have affected the usability of our system, rather than to develop new retrieval applications. We were aware from the outset that our hospital administration had withdrawn support from other clinical computing efforts that had failed. Our goal was to succeed clinically and to operate in a cost-effective manner. We rapidly learned that ideas that were attractive to programmers or that seemed good on paper often did not work well for our bedside users.

We had believed initially that the hospital's interest would be best served by operating with the vendor's standard release systems.

That way, no one person in our own effort would ever become indispensable. However, with each new standard release, we found ourselves undertaking more and more modifications. In fact, our system had never really been standard. Then as we came into contact with other hospital users, we recognized the diversity of needs and opinions among owners of hardware identical to ours. It became clear that no standard release could meet the requirements of all customers. If anyone was to be responsible for the successful operation of our system, it was we, and not our vendor.

Improving Data Capture/Input

As we became increasingly aware of the vulnerability of the system to incomplete records, we reconsidered the whole data-capture process. Cards, which had saved us from many early disasters, became outmoded as we developed a magnetic tape transaction log. Cards had to go. But that left only terminals. Our nursing computer committee told us that terminal data entry was too tedious and slow.

To deal with the data-capture problem, we first looked at optimizing the "standard" entry subsystem. Finding this still too slow, we looked at new approaches to minimize disk transactions that were the limiting factor in system performance. This has meant the development of more effective methods of display configuration, as well as analysis of various data entry tasks to permit the system to anticipate entries and carry forward repetitious data (e.g., formula type or intravenous content information). The result has been an entry package that is three to ten times faster than our previous best effort, with a 75 percent reduction in needed key strokes. Test runs of this program were received very favorably by our nursing staff, and the subsystem has been loaded permanently. Now that the card readers are gone, data are recorded at the time they are received. Bedside data are now more than 95 percent complete, and virtually all patient data are current within the last hour.

Improving Data Retrieval/Output

Our earliest efforts were aimed at improving retrieval times. At first, while the system was looking for data, a DATA RETRIEVAL IN PROGRESS message was placed on the screen. When all data were in place, the final display was written. We found that our users often thought the system was dead if the pause was more than a few seconds. We therefore attempted to show signs of life, labeling the screen for the pending display and writing data in as soon as they became available. This got good results. We also had some lessons to learn about screen layout, as mentioned above: Confused users stop using.

In attempting to improve the user's interaction with the computer during data retrieval, we found that many of the same considerations that had improved data entry were applicable. Program design was more successful if the programmer had developed a detailed understanding of the user's specific needs. It is often possible to anticipate a user's needs for specific types of information and to have them ready when requested. This avoids the delay imposed by the disk search. Although the actual response time of the system in this case does not really change, the user perceives a dramatic improvement when data are ready and waiting.

With complete records, doctors are now turning increasingly to the system for both raw data and analyses of data, such as fluid and caloric intake calculations. They are even beginning to suggest new programs that would help in patient care. Our current activities in the area of improved retrieval or data output generation from the system include most of the potential "benefits" of a computerized medical data system mentioned earlier. The system is programmed to map selected data into long-term data bases. We are doing waveform analysis and a variety of types of pulmonary function testing in infants. A large number of reports aid in the administrative operation of the unit, from physician billing and insurance data to progress reports for referring hospitals. We are also about to begin to use the system to provide more flexible scheduling for the more than 120 nurses who work in our NICU.

FINANCIAL CONSIDERATIONS

Minicomputer systems can be cost effective in patient care applications provided they deliver necessary services that would ordinarily incur additional expense. While improved patient care is often considered the major benefit of effective information management, it has no definite monetary value. Usefulness is also a matter of one's point of view. Once data are available for patient care, the detail of reporting to the permanent record is of little importance to the clinician, yet hospitals spend large sums on manual charting of lab data. An effective information system should meet both the clinical need for data and the administrative need for documentation. Improved patient care can be considered the by-product of automated clerical work.

Using our example, the New York Hospital-Cornell Medical Center installation for the NICU cost approximately $350,000. This installation was paid as a 5-year lease and is reimbursed as an operating cost by third-party carriers. The annual lease payment was $70,000. Service, supplies, and salaries added another $45,000 per year. The annual cost was $115,000, or $6.30 per patient day. Charting laboratory values for the expanded ICU would have required between seven and 10 additional chart clerks to provide service for three shifts, 7 days a week. Salaries and fringe benefits for seven clerks would have cost about $100,000. A second service the information system can perform that carries a tangible value is the generation of a magnetic tape for billing for laboratory tests, which eliminates keypunching the data. The value of this tape is approximately $50 per day, or $18,250 per year. On the basis of these two services alone, the system would be considered cost effective.

Since the expiration of our lease in April 1981, expenses have been limited to salary costs for the programming staff and for a service contract on all equipment. Total annual expenses are now between $75,000 and $80,000. Additional software programs were written that have significantly reduced the need for clerical staff, representing further cost savings.

CONCLUSION

Reliable storage and retrieval of patient data is the cornerstone of any comprehensive clinical computing effort. Its long-range success hinges on acceptance by the primary user in the clinical setting and on financial acceptance by the institution. Both factors can be influenced by initial planning and long-range program development. Dedicated minicomputer systems offer the autonomy enjoyed by microprocessors coupled with the computing power, storage, and communications capabilities of larger systems. System costs can be justified by the value of clerical services that can be automated. Once reliable operation of a bedside data management system has been achieved, its data base can be used or expanded to accommodate virtually any perinatal computing application.

REFERENCE

1. Frayer WW: Patient data management in neonatal intensive care. Clin Perinatol 7: 145-154, 1980.