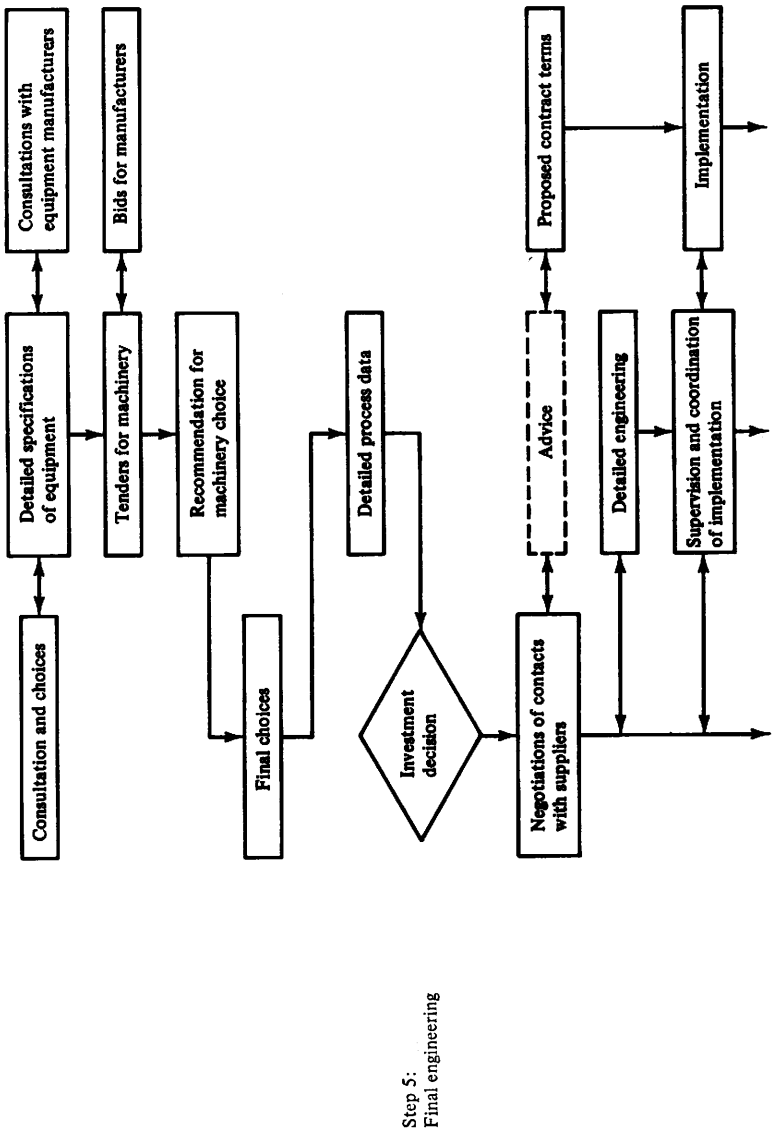

Figure 6.2
Choice-of-Technology Decision Process in the Pulp and Paper Industry

Preliminary Studies

The next step is to define the technical parameters of this project opportunity. These deal mostly with two subjects: the wood supply and the chemical transformation process. If the project is to use natural forests as its source of raw material, inquiries must deal with the species of wood available, its chemical properties, and the area that will have to be harvested to provide a continuous supply of wood for a mill of the scale contemplated. If the project is to grow its own wood supply, soil analysis, growth rate studies of different species, and planting and logging schedules have to be made.

The characteristics of the wood to be used and the volume in which it is expected to be available will allow for an identification of the process (or processes) to be employed in order to obtain a paper of given characteristics at the lowest cost. To assess the response of the type of wood available to different pulping processes, pulping tests will often be made, either in other plants of the company or in laboratories. Through these tests a first evaluation of the chemical requirements of the mill will be made. At this stage, however, the pulping process will be defined only in general terms (such as sulfate or sulfite), and neither the exact sequence of processing steps nor the types of equipment to be used will have been determined yet.

These preliminary studies are generally conducted with the assistance of outside consultants. Although the largest pulp and paper firms might have the capacity to do these studies internally, they prefer to use outside consultants to avoid overburdening their internal research and design capacity. By using outside consultants, a firm also secures an independent opinion and takes advantage of the pool of knowledge accumulated by organizations that are dealing with all of the main pulp and paper equipment manufacturers and that therefore could have a better knowledge of recent industry developments.

On the basis of the broad project description developed at this stage, it will be decided whether to pursue a more detailed analysis of the project. A selection might also be made among different investment opportunities or alternative project concepts. Even at such an early stage, however, the number of alternative project concepts considered is generally quite limited since the raw materials available and the market opportunities determine to a large extent the main characteristics of the potential project.

Process Development

The third stage in the evaluation process may be called the prefeasibility stage. As far as technology choice is concerned, it is at this stage that the development of the production process takes place. The help of a general pulp and paper consulting and engineering firm becomes indispensable from this stage on. This consulting firm might subcontract some specialized aspects of the inquiry, such as forestry studies or the testing of pulping and bleaching reactions, to specialized firms or research institutes.

The task of the general consultant is to refine the project description developed previously and arrive at a precise process outline. This outline shows the main characteristics of the transformations performed and defines in general terms the equipment required in each of the processing steps. The consulting firm generally prepares this outline by drawing on its accumulated knowledge about equipment that can be manufactured by different suppliers. Sometimes preliminary contacts with equipment manufacturers are initiated in order for these manufacturers to propose technical solutions to specific problems.

At this stage the technology choices for the processing equipment are made. Since detailed specifications have not yet been developed, these choices are based on rough estimates of input requirements. Thus only the most crucial variables in the efficiency of the process are investigated and influence the selection.

A list of equipment suppliers that can supply the types of equipment required by the mill might also be drawn up. For most pieces of equipment, however, this is not necessary since the technical choices made about the process and the overall equipment specifications developed reduce this list to a very short one, if not a single name.

At this point the elements needed for a preliminary evaluation of the investment cost, the manufacturing cost, and the profitability of the proposed venture are available. On the basis of these estimates the project sponsors will decide whether to proceed to the final stage of analysis, to abandon the project, or to redirect it by changing some of the basic assumptions on which it has been conceived. Redirecting the project, however, means that some of the analysis already performed will have to be redone.

Detailed Specifications

In the feasibility study stage of the project evaluation, a detailed definition of the different aspects of the project is made, from logging schedules to financial projections. From the production technology side this entails developing detailed specifications for all of the equipment required on the basis of process flow and material balance computations. This is normally done by the general consulting firm in conjunction with both the project sponsors and the equipment suppliers. Once the detailed equipment specifications have been worked out, bids are requested from the manufacturers.

The terms of these bids are generally defined by the consultant, who will also review the submissions. For technical as well as economic reasons competitive bidding by several manufacturers is the exception rather than the rule in the pulp and paper industry. The submission of a bid for large pieces of equipment such as digesters, recovery boilers, evaporation towers, and paper machines involves so much engineering work that a manufacturer cannot reasonably be expected to incur these costs without some assurance of an order.

After the bids are received and analyzed, detailed process data will be generated. It is then possible to make precise estimates of investment and production costs and, on the basis of these, develop a set of revised and far more reliable financial projections that are critical to the sponsors' final investment decision.

Therefore it is only very late in the planning and design of a pulp and paper mill that precise cost and input requirement estimates can be made. To generate the detailed specifications needed for such estimates, extremely large amounts of time and money must be spent. At this stage only drastic discoveries would result in changes in the project's design. Choices such as those dealing with technology have to be made much earlier and are therefore based on approximate data.

Detailed Engineering and Implementation

The decision to proceed with the project does not mark the end of the engineering studies nor of the technical-definition process. The final negotiations with the equipment suppliers that are initiated at this point include a definition of the last technical details of the equipment. It is also at this stage that the instrumentation and control equipment for the mill is defined precisely. On the basis of these exact descriptions and specifications, the detailed engineering of the plant is made by the general consultant. This same consultant will then coordinate and supervise construction, training of the workers, testing, and start-up and commissioning.

The Choice of Technology for Processing Equipment

Processing equipment is defined as all of the machinery that transforms the product or one of its inputs. It excludes handling and transfer equipment, as well as instrumentation and control systems.

Scale of Production Considerations

The choice-of-technology decision for processing equipment was found to be primarily a function of scale considerations. The relative efficiency of the alternative machine technologies identified earlier proved to be a function of scale rather than of the cost of the factors of production.

The factor requirements of these alternative processing technologies can be determined only by means of extensive testing and lengthy design effort, making it impossible to arrive at a systematic, quantitative appraisal of the impact of scale on their relative efficiency. For the most important processing steps it is, however, possible to estimate this relationship between scale and relative efficiency of alternative technologies, as well as its impact on capital labor usage.

Digesting Step

There are two basic alternative technologies in the digesting step: batch digesting and continuous digesting. Batch digesters are characterized by a low capital cost because they are nothing more than large pressure vessels in which wood chips and chemicals are mixed and then subjected to high temperature and pressure before being drained off for further processing. Continuous digesters, on the other hand, have a much higher capital cost for the same processing capacity. They incorporate sophisticated feeding mechanisms capable of introducing wood chips and chemicals into a vessel that is constantly kept at high pressure and temperature. Continuous digesters also require an internal transport mechanism capable of carrying the wood chips through the digester while they are submitted to the various phases of the cooking cycle. Unloading of the output is also done in a continuous manner by means of a mechanism that prevents a loss of pressure or heat from the digester.

At a given scale of production the main advantage of the continuous technology is that it operates without surges in demand for wood, chemicals, steam pressure, and heat and in supply of digested pulp. The elimination of surges, in turn, allows for a reduction in the planned capacity of the facilities that produce these inputs or in the need for intermediate storage capacity. The investment required in such facilities is therefore reduced.

How does scale of production influence the relative efficiency of these two technologies? The answer is that while the cost of a digester, whether batch or continuous, increases less than proportionally to its processing capacity, batch digesters have a maximum capacity of 80 to 120 tons per day while continuous digesters can have a daily capacity of up to 1,200 tons. Therefore the investment cost of a daily ton of continuous digesting capacity decreases until 1,200 tons of daily capacity, while that of batch digesting capacity remains roughly constant above 120-ton-per-day capacity. It is estimated that for a plant with a 250-ton-per-day capacity, the capital cost of installing three batch digesters or one continuous digester is roughly equal. For a plant with a 500-ton-per-day capacity, however, the capital cost of one continuous digester is 25 to 30 percent lower than the cost of five batch digesters. This gap between the capital cost of the batch and the continuous alternatives keeps widening as the scale of operation increases up to 1,200 tons per day, the maximum capacity of a continuous digester.

Trade-offs between capital and labor in the pulp and paper industry are to be found in the choice of instrumentation and control equipment rather than in the choice of technology for the processing equipment. This is clearly the case in the digesting step. Whether batch or continuous digesting is selected, a choice must be made regarding the degree of automation of the instruments and controls that will equip these digesters. The range of available alternatives extends from the separate manual control of each digester's individual functions to the integration of the digesting step into a computer control system for the entire pulp mill.

This does not mean, however, that the choice between batch and continuous digesters—while itself mainly dependent upon the scale of operations—does not have important implications as to the amount of employment created by each of the alternative control technologies. All available control technologies may be used to operate batch as well as continuous digesters, but the amount of employment each would generate depends upon the type of digester whose operations it governs.

Table 6.1
Number of Operators per Shift Required for Digesting Step of Mills of Various Capacities and Technologies

Capacity	250 Tons per Day		500 Tons per Day	
Control technology	Alternative 2 Manual on Location	Alternative 5 Automatic Step Panel	Alternative 2 Manual on Location	Alternative 5 Automatic Step Panel
Batch digesters	3	1	5	1
Continuous digester	2	1	2	1

Note: See table 2.3 for a more detailed definition of alternative technology levels.

In other words the choice between batch and continuous digesters sets a range for the number of jobs that can be created by the instrumentation and control decision. Table 6.1 indicates the number of operators required by a 250-ton-per-day and a 500-ton-per-day digesting step equipped with either batch or continuous digesters, for two alternative levels of sophistication of control equipment.

The manual control of one batch digester, regardless of size, requires one operator; the manual control of one continuous digester, also regardless of size, requires one operator and one helper. Therefore under the manual option, larger plants require more batch digesters, and as a consequence more workers. But, if equipped with a continuous digester, a larger digester can be used without any change in employment. The automatic control of the digesting step from a step control panel requires one operator, regardless of the digester technology adopted and of the number of digesters. With this control technology the amount of employment generated in the digesting step is therefore independent of the capacity of the mill. Consequently, as table 6.1 shows, batch digesters tend to offer a wider range of capital-labor trade-offs in the choice of instrumentation and control technologies than do continuous digesters. Efforts to take advantage of economies of scale through the choice of processing equipment result in this case in a narrowing of the scope of possible adaptation to differences in the relative cost of capital and labor.

Papermaking Step

Another example of the way in which economies of scale influence the relative efficiency of alternative technologies, and thereby fix the range of economically feasible capital-labor mixes, can be found in the papermaking step. A number of technological innovations in papermaking machinery have made possible increases in machine speed and machine width, thereby allowing for much higher production capacities per machine. The labor requirement, on the other hand, is about the same—at a given level of instrumentation and control technology—for all paper machines whatever their production capacity may be. Depending upon the instrumentation and control technology adopted, between five and ten workers are needed to operate a paper machine. The relationship between price and production capacity of paper machines, however, is such that to obtain a given volume of production, it is more economical to install one paper machine of a newer technology than two of an older, simpler technology and half the capacity each. From the employment-creation point of view, the one paper machine solution will require half the number of operators and two-thirds the total employment of the two machine solution. (The percentage reduction in total employment that the one paper machine alternative represents over the two paper machine alternative is smaller than the percentage reduction in the number of operators because these two options require the same number of highly skilled maintenance workers.)

Table 6.2 presents a comparison of the investment and labor cost increases associated with increases in machine width and speed. It also provides a comparison of investment and labor costs of the two alternatives for a given production level: one fast and wide machine (column D) versus two slow and narrow machines (column E).

Overall Impact

The economic advantage that larger processing units hold in the papermaking step was found to be quite common in the pulp and paper industry and to exist in most other processing steps. It is less expensive, if technically feasible, to buy one large piece of equipment capable of processing all of the mill's needs than two pieces of equipment of half that capacity for the recovery boiler, the evaporation towers, the lime kiln, and several other main pieces of processing equipment. This investment-cost comparison is all the more true when building costs are included in the cost estimates. At the same time the number of operators needed for a given instrumentation and control technology is proportional to the number of units (except in the case of automatic centrally located controls that operate all of the pieces of equipment of a processing step or mill section—technology levels 5, 6, and 7 in

Table 6.2
Increases in Machine Cost and Employment Associated with Increases in Paper Machine Size

	A	B	C	D	2 machines E[a]
Speed (feet per mn)	1,250	1,250	1,700	1,700	1,000
Width trim (inches)	244	305	244	305	244
Production theoretical (t/day)	195	243	265	330	312
Efficiency (%)	94.5	94.5	90	90	95.5
Production actual (t/day)	184	230	239	298	298
Production actual (index)	100	125	130	162	162
Machine Cost (index)	100	111	113	124	185
Operating labor cost (index)	100	102.5	107	110	195
Maintenance labor cost (index)	100	121.5	132	164	170
Total labor cost (index)	100	106	112	120	190

Note: Estimates made on the basis of an identical instrumentation and control technology being used in all the cases.
a. Two machines.

table 2.3) rather than to the unit's size. The impact of such economies of scale on the amount of employment that results from the application of the same control technology in mills of different size is shown for an entire pulp mill in table 6.3.

Flexibility and Risk Considerations

While cost considerations justify the choice of the largest possible processing units, given technical and market constraints, two noncost considerations temper such a tendency.

The first consideration that argues for the adoption of several small units rather than one large one is flexibility of production. Paper consumption in developing countries is low. In 1975 developing countries, with a population more than twice that of developed countries, consumed only 11.8 million of the total 133 million tons of paper and paperboard produced in the world. For this reason pulp and paper mills in developing countries must produce a much wider range of paper types than developed countries' mills in order to attain minimum economies of scale. If they were to use large units with high production capacities, these mills would have to stop production often in order to

Table 6.3
Scale of Production and Employment Generation in Bleached Sulfate Pulp Mills

Production capacity (t/day)	150	225	300	450	600
Production capacity index	100	150	200	300	400
Total investment index	100	122	148	187	234
Total employment index	100	127	140	165	180

Note: Estimates made on the basis of identical instrumentation and control technology being used in all cases.

clean and readjust these units before starting production of a different product type. Although small and more numerous units are more expensive to buy and operate, they have the advantage of providing savings on downtime by allowing specialization of the different units in the production of the various types of pulp or paper required.

This consideration was found to play an important role in the selection of technology for digesters and paper machines. Managers of medium-sized pulp and paper plants in developing countries producing for the local market stressed the importance of this consideration in explaining their choice of several batch digesters rather than of one continuous digester and of several small paper machines rather than one large one. In contrast export-oriented mills opted for one large digester and one large paper machine because they were able to specialize in the production of one type of pulp and paper.

The second consideration that tends to justify the choice of several small units rather than one large one is risk minimization. If one piece of equipment must fulfill the needs of an entire mill and this unit breaks down, the mill is inoperative until that unit can be started up again. If several pieces of equipment operating in parallel perform that same operation, it is highly unlikely that all of them will break down at the same time. In fact by somewhat overburdening the other units and rescheduling maintenance stoppages, it is often possible to make up for the temporary loss of production capacity in one step and to keep the rest of the mill operating at full capacity. For the same reason batch processing technologies equipped with intermediate storage facilities between processing steps are often preferred to continuous processing technologies. In case of a short breakdown in one step, the rest of the production process can continue operating at full capacity by processing some of the intermediate product in storage.

Because of a lower overall level of training of the workers and of a scarcity of good maintenance personnel, planners and managers of pulp and paper facilities in developing countries felt much less confident of being able to avoid breakdowns than their developed countries' counterparts. Lack of support services and distance from the equipment suppliers also increased the time required in developing countries to repair such breakdowns. For these reasons risk minimization considerations were found to have played an important role in the choice of smaller units and discontinuous processes by the firms studied. The importance of risk minimization considerations was confirmed by the fact that in some crucial processing steps where a processing unit can be added at a reasonable cost, several plants installed one more unit than was actually needed. Such was the case in the digesting step when batch digesters were used.

The effects of flexibility improvement and risk minimization are difficult to dissociate from each other. They have the same influence on the choice-of-technology decision and are usually found together, except in the case of mills producing for export. Taken together they seem to have most influenced the choice of processing technology among medium-sized mills. While large-sized mills (above 400-ton-per-day capacity) were found to have always chosen the large, continuous units option, medium-sized mills (250 to 400 tons per day) were found in all cases but one to have selected the small, more numerous units. Pure cost of production considerations still favored the large, continuous unit alternative in these medium-sized installations. It appears, however, that in their case the production costs of the two alternatives were considered close enough for flexibility and risk considerations to tip the scales in favor of the small-units option. For large-sized mills, on the other hand, the cost advantage of large, continuous units appears to have been too important for flexibility and risk considerations to affect the decision.

The Choice of Technology for Materials Handling Equipment

Handling and transfer operations can be divided into four groups: the handling of the wood in the wood yard, the transfer of the chips between the chippers and the digesters, the transfer of the pulp among the various pulp processing steps, and the handling of the paper at the end of the paper machine. Theoretically all of these can be performed manually, and this is the way the handling was in fact done a century ago. Pulp from the digesters, for example, was dumped on the floor of the pulp mill after cooking, and workers would then roll it to the next step in wheelbarrows.

Increases in the scale of production, as well as stricter health and safety standards, have made the manual transfer of the pulp impractical, even for very small mills. The manual loading of chips into the digesters has also become uneconomical because of the relatively low cost of automatic loading systems and because of the increase in the cost and length of downtime that would result from the use of manual loading methods on digesters of larger and larger capacity. The increase in the size of the paper rolls that came about with increases in the speed of the paper machines have made their manual handling physically impossible. Furthermore automatic paper-handling techniques make it possible to unload the paper machine without stopping it and therefore without loss of productivity. There again increases in the speed and width of the paper machines have resulted in an increase in the cost associated with any stoppage of the machine, thus making nonautomatic handling equipment uneconomical.

In the wood yard, on the other hand, a considerable amount of adaptation to the relatively low cost of labor in developing countries is still possible. Nevertheless it was found that the larger the mill, the less labor intensive the technologies adopted to perform wood yard operations tend to become. In mills of less than 100-tons-per-day capacity, all wood yard operations, including in some cases the debarking of the trees, were performed manually or with simple equipment such as handcarts. In contrast mills of 400-tons-per-day capacity or more, confronted with the same factor prices, used cranes and moving belts for these operations. The explanation given by the managers of these large mills is the existence of diseconomies of scale in the use of the labor-intensive methods above a certain volume of operations. The manual unloading of the larger trucks required to supply large mills takes longer and reduces the efficiency of use of these trucks. Since the height to which wood can be stacked manually is limited, the wood yard must also be expanded, resulting in a longer average journey to the chipper. The practical capacity of a chipper is usually determined by the speed at which it can be fed. The physical movement of workers around the unit imposes a fairly low limit of the speed of manual feeding. Once this limit is reached, the choice is to install a second chipper or to shift to automatic feeding.

In cases where it was possible to compute the processing cost of the alternative handling technologies, management choices seemed to be justified on pure economic grounds. No significant biases toward greater capital intensity or labor intensity than economically justified were found in these choices. Three characteristics of wood yard operations explain this readiness to adapt to local factor prices. First, the wood yard normally operates on two shifts and is separated from the rest of the process by a large inventory of wood chips. Therefore any shortfall in the wood yard output does not immediately affect the rest of the process and can easily be made up by overtime work. Second, the operations performed in the wood yard are such that workers' mistakes are of little consequence. Finally when performed manually, the wood yard operations may be subcontracted to outside firms that handle worker relations. Such subcontracting isolates the firm from some of the risks and problems associated with a large labor force.

The Choice of Technology for Instrumentation and Control

The choice of instrumentation and control systems is the main source of capital-labor trade-offs in the pulp and paper industry. One would therefore expect the choice of instrumentation and control technology to be made on the basis of comparisons between the cost of labor and the cost of the equipment that can replace this labor. Instead management's concern with the risk of worker error and the supply of instrument maintenance workers turned out to be the overriding considerations in deciding on the degree of complexity and automation of this equipment. While concern about the risk of worker error tended to promote the choice of more centralized and automated controls, this thrust toward automation was limited by the scarcity of maintenance personnel. The balance struck between these two conflicting considerations seemed to hinge upon the characteristics of the processing step for which the choice was being made, as well as upon the scale of production.

Cost of Human Error

The large-scale nature of the pulp and paper industry and the sensitivity of the process equilibrium make a control error potentially very costly. The consensus in the industry is that such an error or faulty timing is more likely if the control function is performed by a worker than if it is performed automatically, provided that the instruments and automation mechanisms are properly maintained. Moreover it is generally agreed that where manual controls are involved, the risk of error increases with the number of workers involved in this control function. Thus the risk of error is considered greater when several workers manually operate controls located on the equipment itself (alternative technology 1) than if these instruments and controls are centralized at one control panel and operated by a single worker (alternative 3). Yet even this technology is perceived as being more prone to error than one in which these controls are automatically activated when the measured variables reach preset values (technology 4), assuming proper maintenance of these automatic mechanisms.

Theoretically the risk of error should be incorporated in the economic evaluation of different instrumentation and control technologies. By estimating the probability of an error's occurrence during a given time period, as well as the cost of such an error, an expected cost of workers' errors would be obtained. This cost should then be added to the cost of the labor-intensive technology before it is compared to the more capital-intensive one. Such a procedure was followed when the cost of a possible error was thought to be relatively small. In that event a more or less formalized computation of the expected cost of an error would enter the evaluation of alternative technologies. When the cost of an error was considered to be large, the likelihood of its occurrence no longer seemed to play a role in the decision; the manual control alternative would be discarded.

Although managers could not identify what they considered large costs of error, an examination of their choice of control technology decisions revealed some clear criteria. In the plants visited an error whose cost would be considered large and therefore unacceptable was one that could result in serious injury to the workers. For example, vessels operating under high pressure and temperatures normally would have their pressure automatically controlled; the level of corrosive chemicals in tanks would also be automatically controlled; and dangerous operations, such as couching when the paper machine is started, would be automated. A second type of error whose cost was considered excessive was one that would have consequences not only for the processing step in which it occurred but for other steps as well. Such errors would be those that take place in pieces of equipment that play a crucial role in the manufacturing process. As in the textile industry a piece of equipment is considered crucial if it is important in determining the quality of the end product or if it processes the entire production of the plant. Continuous digesters are an example of such pieces of equipment. They are crucial in the determination of the quality of the pulp and normally process the entire plant's output. Batch digesters, on the other hand, are generally considered less crucial since several of them usually operate in parallel. This explains the higher level of automation found among continuous digesters than among batch digesters.

Availability of Instrument Technicians

The maintenance of automatic instruments and controls is felt to require a high degree of skill and a long period of training, even in developed countries. Such skills are rare in developing countries, no matter what price a firm is willing to pay, short of bearing the cost of expatriates. This difficulty in finding qualified personnel for the maintenance of instruments and automatic control systems affects the choice of instrumentation and control technology in an opposite manner than human error. It motivates the adoption of simple, labor-intensive systems in much the same way as the risk of human error promotes the adoption of automated systems. Instrument and control equipment malfunctions resulting from inadequate maintenance are associated with costs in the same way as human errors are.

To limit the extent of such maintenance problems, the firms that were investigated avoided adopting the most sophisticated instrumentation and control systems. Computer-controlled systems, for example, were never considered to be a viable alternative because of the extremely high level of skill required from the maintenance and operating personnel. Firms were also found to rank processing steps in terms of the priority given to their automation and to automate them in that order according to what they felt was the availability of qualified maintenance personnel. This order of priority was consistent with the definition of crucial steps. Therefore firms with access to a larger supply of personnel with maintenance skills would tend to automate a larger number of operations than would firms faced with difficulties in obtaining these skills. For example, some firms would increase the level of automation of their plants on the occasion of an expansion. Such choices are explained by the fact that at the time of the expansion, these firms had already developed their maintenance work force and therefore felt more confident in adopting a higher level of automation.

Table 6.4
Control Technologies Used by Different Types of Pulp and Paper Mills

Processing Step	Control Variable	Alternative** 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Digester	Chip feeding	@ 0	#					×
	Flow of liquor		@ 0	#				×
	Flow of steam		0		@	#		×
	Unloading of digester	@	0	#				×
	Cycle control			@ 0		#		
Blow tank	Pressure control			@ 0		#		×
	Flow of water			@	0	#		×
	Outflow of pulp			@ 0		#		×
Defiberizers	Flow of pulp	@ 0			#		×	
	Speed of surfaces	@ 0			#		×	
	Pressure	@ 0			#		×	
Screens	Flow of pulp	@ 0			#		×	
	Pressure	@ 0			#		×	
Washers	Flow of pulp	@ 0		#			×	
	Flow of water	@ 0			#		×	
	Speed of drums	@ 0		#			×	