INTEGRATED COMPUTER SYSTEMS IN THE PULP AND PAPER INDUSTRY

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PREFACE

Today, continuing rapid development and remarkable change are seen both in management systems and in production-related control and information systems in the pulp and paper industry. New hardware, based on recent advances in microelectronics, has presented totally new technical possibilities. This has led to the concept of integrated hierarchical company- and/or mill-wide information and control systems.

In order that the new systems and technical solutions can be made effective and useful, the experiences, needs, and opinions of existing and potential users of these systems are important. At the International Institute for Applied Systems Analysis (IIASA) a project to study the long-term development and problems of the forest industry was initiated in 1979. One of the main topics in the project proposal was the development of integrated computer systems. Later, the emphasis of the project progressed to other topics, but it was decided that a detailed survey of users was essential.

A detailed questionnaire was sent to over 240 major forest industry companies in 17 countries. This paper reports on the results of this survey in a relatively condensed form. It is the hope of the author that the report will be useful and interesting to people developing and working with these systems in the forest industry and that it will be valuable to IIASA for planning further activities in this area.

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SUMMARY

Management systems and process control systems in the pulp and paper industry have so far been typically developed, used, and maintained separately. However, the recent rapid development in hardware and the results from theoretical studies of hierarchical systems now make it possible, and promising, to combine these systems into a hierarchical mill-wide or even corporation-wide management, information, and control structure. This report presents the results of a survey carried out by the International Institute for Applied Systems Analysis (IIASA) in 1980–81. The results of theoretical studies and prototype projects and the opinions and experiences of users of such systems are analyzed in detail. This investigation shows that the hierarchical approach at the mill level is desirable and that it will be implemented to a larger extent during the next five years. However, at the company or corporate level the development and potential advantages of these systems are not so clear.

1 INTRODUCTION

Rapid developments in control theory, management science, operations research, instrument technology, electronics, and computer science have led to rapid changes in the operation and management of mills in process industries since the early 1960s. Evidence of these developments can also be seen in the forest industries, especially in the pulp and paper industry.

There was great enthusiasm during the early stages of the development of computer applications in the pulp and paper industry. For example, ambitious plans were presented for controlling a whole paper mill with one big computer, which was also to perform management tasks. The early 1960s were a time of exploration and experiment and, unfortunately, many projects failed. Pessimism and stagnation were the result. The reasons for this were quite clear (Uronen and Williams 1978):

1. The problems and difficulties to be overcome were underestimated: for example, too few personnel, too tight a time schedule, and a limited budget.
2. The reliability, speed, and capacity of the computers then available were not sufficient for the tasks.
3. The necessary instrumentation and plant process mathematical models and algorithms were lacking.
4. There was a shortage of competent and specially trained personnel for the development and project groups.
5. There was reluctance on the part of management and operators.

After a few years' delay, the era of the minicomputer, which began in the second half of the sixties, brought new possibilities, especially in the operational and process control of the mills. Thus complex, packaged computer control systems were developed for certain well defined subprocesses. This approach in mill process control has proved successful, for the following main reasons (Uronen and Williams 1978):

1. The systems were developed through cooperation between computer specialists and user–engineers to solve minor and well defined problems.
2. The specialists and engineers had the necessary instrumentation, process models, and algorithms as background.
3. The minicomputers were already sufficiently reliable and capable to handle these smaller problems.
4. The economic results of using these systems could be verified in a reasonable time.
5. The problems of the man–machine interface were noted and solved with the technology available.

The success of these systems led to a rapid increase in the number of process control systems in the pulp and paper industry. The most common applications were for paper machine control packages (basis weight and moisture control), stock preparation systems, digester control systems, and bleach plant control systems. With the sudden and continuing increase in energy costs after 1973, the interest in computerized energy management systems and boiler control systems led to more of these systems being used.

At the same time as the minicomputer-based process control system was making its breakthrough, there was a remarkable improvement and change in the use of computers for management and business. These computers have become more powerful, have more efficient operating systems, and use high-level languages, and their performance:cost ratio has become much more favorable.

The situation in the pulp and paper industry today is such that real-time process control systems and batch-type management systems are widely used. Unfortunately, there is little or no exchange of information or coordination between the two types of system; normally, different organizations use and maintain them.

Today there is rapid development in both process control systems and management information systems used in mills. The latest advances in microelectronics have resulted in digital instrumentation systems and other distributed control systems, which provide new opportunities for effective automation, coordination, and optimization in all production operations, including higher-level scheduling and planning functions. The classical control room instrumentation is also undergoing rapid change. The control room of the 1980s will be equipped with interactive multicolor video display units, graphic units, and so on, and the traditional recorders, counters, and indicators will gradually diminish in number. These developments will change the management of mill operation. For example, control of cost and efficiency will be enhanced because cost and effectiveness figures will be available in real time.

The dynamism and complexity of the business and of the economy are continuously increasing. Existing methods of management will no longer be able to cope. There is also an increasing awareness that accurate and real-time information about industrial processes is a vital resource for the company and its business environment. Therefore, effective information, control, and management systems are needed throughout the organization. This will also mean a change in style from accounting-oriented management to information-oriented management.

Today there is a trend toward satisfying this need to include all these separate and uncoordinated systems into one mill- or company-wide integrated system according to hierarchical concepts (Uronen 1979, 1980a, b, 1981). Figure 1 shows the three generations of computer-based systems in the pulp and paper industry.

Many advantages are to be gained by implementing such an integrated system policy. However, there are also a lot of difficulties in defining the correct hierarchies. The main question is how to link the management systems with the process control systems, and to what extent. In other words, which one of the schemes in Figure 2 is the best or optimum for different types and sizes of organization, or are there still other types of solution?

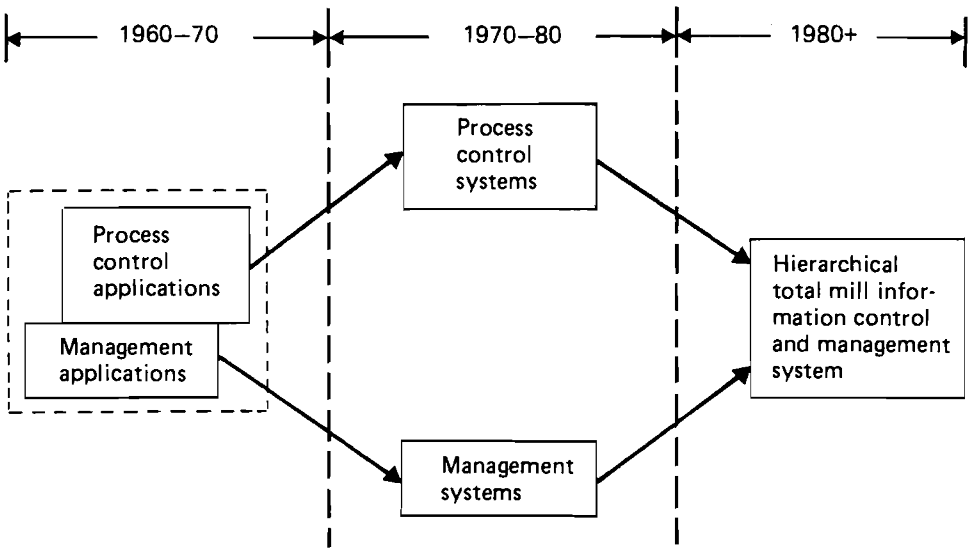

FIGURE 1 Three generations of computer systems. Characteristics: 1960–70, centralized hardware, "big" computers, in-house systems; 1970–80, minicomputers in process control, separate organizations and systems, packaged systems, mainframes in management applications; 1980+, distributed hardware, hierarchical structure, integrated systems.

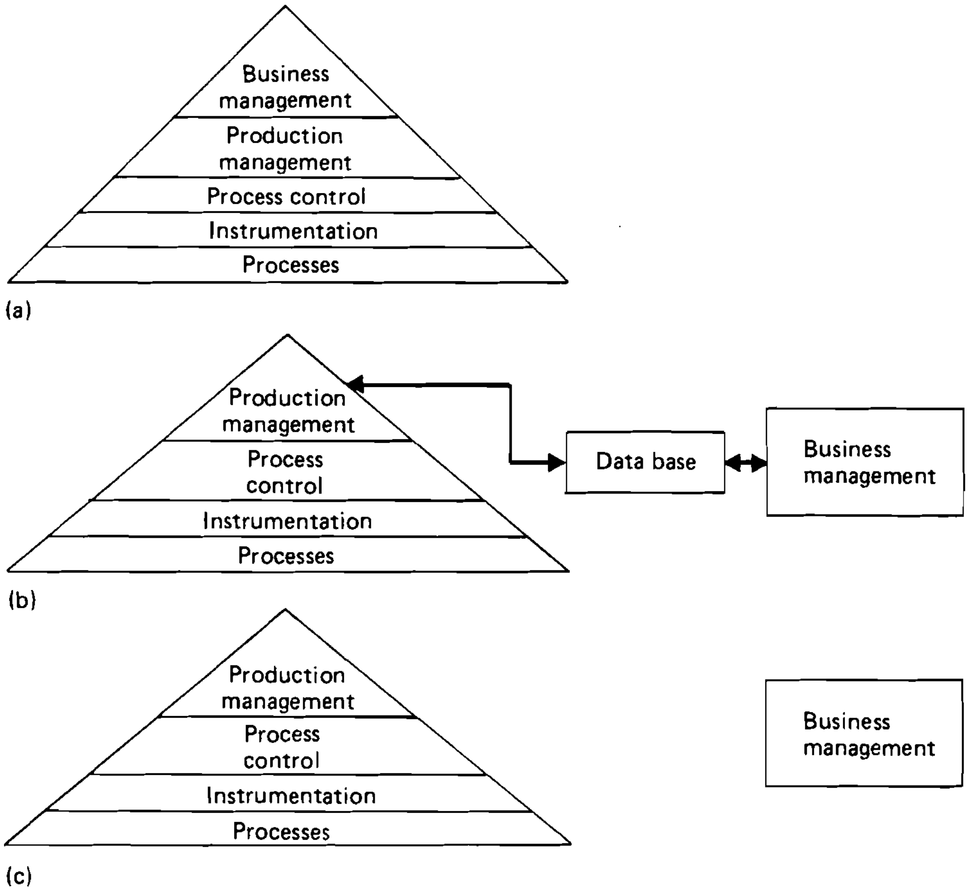

FIGURE 2 Different degrees of integration: (a) full integration; (b) real-time communications and common data bases; (c) full separation.

These questions were the basis for the study at IIASA in 1979. The only way to explore the future in this area is to ask the companies and people using such systems in industry to state their opinions, needs, and suggestions, including criticisms of existing systems and proposed trends and new directions. Therefore, a detailed questionnaire was sent to about 240 forest industry companies mainly producing pulp and paper in 17 countries: Austria, Canada, Finland, France, the Federal Republic of Germany, Hungary, Italy, Japan, the Netherlands, Norway, Portugal, the Soviet Union, Spain, Sweden, Switzerland, the United Kingdom, and the United States. This questionnaire is included as the Appendix.

Thirty-nine completed questionnaires were returned, a response of about 16%, which can be regarded as normal in this type of investigation. The results will now be presented, together with a detailed discussion of the state of the art and trends in process control systems, management systems, and integrated mill- and company-wide systems.

2 PROCESS CONTROL SYSTEMS

As stated previously, computerized process control in the pulp and paper industry is about twenty years old (Uronen and Williams 1978) and already the third generation of control systems is in use. After "big" computers, like the IBM 1800, in the early sixties, came the minicomputers, such as the PDP-8, and packaged systems, and now we have microprocessor-based, distributed digital instrumentation and control systems. The total number of such systems in the world's pulp and paper industry is very difficult to estimate, firstly because a computer-based control system is somewhat difficult to define (for example, in the area of order handling and roll handling), and secondly because there are no reliable statistics available.

Rough estimates based on earlier reports (Keyes 1975, Gee and Chamberlain 1977, Uronen and Williams 1978) and an annual rate of increase of approximately 20–25% would lead to an expected number of about 2600 systems to date. Information from the respondents to the questionnaire indicated that they have installed a total of 831 computer-based process control systems at 710 mill sites (approximately 30% of all such systems in the world) (Uronen 1980a). These companies produce about 33 million tons of paper per year, which represents about 23% of the production capacity of the world, and also represent the biggest and most modern companies, on average. This information confirms the estimated total of 2600 systems. Table 1 summarizes the results of the questionnaire concerning the process control systems now in use in the pulp and paper industry.

The following conclusions can be drawn:

- Of the total of 831 systems, 56%, or 464, are packaged systems. Forty-four percent are systems developed in-house or by the user. This result is somewhat different to that obtained by Keyes (1975), for example, who reported 70% to be packaged systems. This change indicates more interest inside the companies, for example, in building inventory control systems, trimming and scheduling systems, order-handling systems, roll-handling systems, and production-planning systems, which, according to the questionnaire, are mainly built in-house.
- There are altogether 208 systems in pulp mills, or about 25% of all systems. The fraction of pulp mill applications, which was about 18% according to Keyes (1975), has increased, but more slowly than expected. One obvious reason is the rapid increase in the number of applications in order handling, roll handling, production planning, and similar processes in paper mills.

Of the pulp mill applications about 47% are packaged systems. This figure is surprisingly low but understandable because for some processes (for example, in the recovery boiler, evaporation plant, lime kiln, and washing and screening plant) packaged systems have been available for only a very short time.

In the paper mills the number of packaged systems is a little higher, about 59%. This is mainly because of the predominance of on-machine packaged systems (about 25% of all systems). A further typical feature of paper mills is the comparatively large number of computerized stock preparation systems, quality-monitoring and quality control systems, trimming and scheduling systems, inventory control systems, and order-handling systems, most of them being in-house systems.

TABLE 1 Summary of process control systems in use.

Application of control system	Number	Number of packaged systems (percentage)	Number of user-developed systems (percentage)
Pulp mills			
Batch digester	40	18(45)	22(55)
Continuous digestion	33	21(64)	12(36)
Bleach plant	42	22(52)	20(48)
Washing and screening	17	7(41)	10(59)
Pulp-drying machine	7	5(71)	2(29)
Evaporation plant	9	2(22)	7(78)
Recovery boiler	21	9(43)	12(57)
Lime kiln and causticization plant	7	2(29)	5(71)
Power boiler	11	5(45)	6(55)
Thermomechanical pulping plant	6	5(83)	1(17)
Grinder	15	2(13)	13(87)
Total	208	98(47)	110(33)
Paper mills			
Stock preparation	51	14(27)	37(73)
Paper machine	225	198(88)	27(12)
Coater	22	20(91)	2(9)
Roll handling	51	22(43)	29(57)
Quality monitoring and control	56	45(80)	11(20)
Inventory	49	8(16)	41(84)
Trimming and scheduling	50	22(44)	28(56)
Energy management	15	8(53)	7(47)
Order handling	59	15(25)	44(75)
Environmental monitoring	8	0(0)	8(100)
Production planning	21	9(43)	12(57)
Production coordination and control	13	3(23)	10(77)
Coating kitchen	3	2(67)	1(33)
Total	623	366(59)	257(41)
Grand total	831	464(56)	367(44)

The classification into packaged and in-house systems is a little diffuse, and a separate question regarding own development by users gave a different distribution. According to the responses, 61% of the process control systems are mostly packages and 39% were developed by the users themselves. Table 2 shows the results concerning the amount of development due to the user and due to the computer companies.

The interesting question concerning plans to install or develop new systems in the near future evoked the responses shown in Table 3. From the table it can be seen that in addition to paper machine systems the new installations planned in the next few years will be concentrated in pulp mills, especially in energy-producing and -consuming processes such as those in the recovery boiler, power boiler, thermomechanical pulping, lime kiln, and evaporation plant.

It was the opinion of 86% of the companies who answered that most packaged systems need some tailoring to suit the requirements of the mill in question. In 78% of the

TABLE 2 Extent of own development by users of control systems.

Extent of own development (%)	Percentage of answers
0–30	52
30–60	19
>60	29

TABLE 3 New systems to be installed.

System	Percentage of answers
Paper machine	39
Bleach plant	31
Recovery boiler	28
Batch digester control	25
Energy management	25
Power boiler	25
Lime kiln control	22
Thermomechanical pulping control	22
Order handling	17
Production control	14
Stock preparation	14
Evaporation plant	14
Continuous digester	11
Coater control	11
Production planning	9
Inventory control	9
Drying machine	9
Washing and screening	3
Roll handling	3
Quality monitoring	3
No specific plans	25

cases this tailoring is handled jointly by the mill and the vendor of the system, which is understandable. In most cases the research and development work in this area is concentrated in cooperation with the vendor (70%). Joint research activities with universities (42%), consulting companies (31%), research institutes (22%), and engineering companies (19%) are also carried out.

A question of great interest is the use of computerized production-planning and control systems connected with the real-time process control systems depicted in Figure 2. This investigation led to the following result:

- Number of companies having such systems: 16
- Number of companies planning to build and implement such systems: 22
- Number of companies having no plans to implement such systems: 8

Here, the total number of companies (46) differs from the number of companies that answered (39) because some companies already have such systems in some mills and are planning to install similar systems in other mills.

Tables 4 and 5 summarize the benefits and drawbacks of computerized production-planning and control systems based on the answers from companies planning to install such systems or from those having negative attitudes toward them. It is interesting that hardware problems have not been mentioned as a reason. Hence the reliability and effectiveness of the existing and available hardware appear to be acceptable and suitable for these tasks.

TABLE 4 Benefits of production-planning and control systems.

Benefit	Percentage of answers
Better use of equipment and capacity	61
Better control of cost and effectiveness	58
Better decision making	55
More accurate and timely information	47
Increased production	75
Decreased losses and risks	37
Easier and more flexible planning	18
Savings in personnel	16
Increased safety in operation	11
Reduction of time loss	3
Better customer service	3
Better inventory management	3

TABLE 5 Reasons not to install a production-planning and control system.

Reason	Percentage of negative answers
High costs	88
Benefits are marginal	75
Difficult and complex programming	75
Lack of models and algorithms	38
Training and education of personnel	38
Attitudes	25
System too complex	13

During the last few years there has been a lot of discussion concerning the ways of building these systems, i.e. should the existing process control systems be utilized as much as possible or should the production-planning and control system be built separately? Of the 16 companies having experience of these systems, five had used the former and 11 the latter method. The most important reasons for this result are the difficulty of combining subsystems from different vendors, i.e. the lack of standardization, and also the fact that, until recently, there had been no compatible systems on the market. The first such systems have recently been introduced (Edlund and Rigerl 1978, Eriksson 1978, Peterson and Rückert 1978, Fowler 1980).

It can be concluded both from the expectations (Table 4) and from the experiences (Table 6) that the most important benefits will be decreased losses and disturbances and better information and decision making, including improved cost control. The more

TABLE 6 Experiences with existing production-planning and control systems.

Benefit	Percentage of answers
Decreased losses and disturbances	81
Better information and decision making	69
Higher production	44
Easier and more flexible planning	44
Savings in personnel	44
Improved timing	7
Problem	
Updating	56
Maintenance	38
Costs	19

"direct" savings, i.e. higher production and savings in personnel, are not at the top of the list. This also supports the fact that the preinvestment calculations of financial benefits from such systems are very difficult to make.

The kinds of maintenance available for the systems in use are described in Table 7. The trend seems to be toward user maintenance. This is especially favored by the self-diagnostic and self-checking features, "change-the-card" hardware, and similar properties of digital microprocessor hardware that make maintenance easier.

Concerning future research and development in process control, the opinions of the users are listed in Table 8. The need for new and better sensors is obvious. It has been at

TABLE 7 Maintenance of the process control systems.

Type of maintenance	Percentage of answers
Vendor ("babysitter")	19
Own maintenance department	35
"Babysitter" and own maintenance department	45
Emergency repairs only	1

TABLE 8 Future R&D needs.

Topic	Percentage of answers
New sensors	61
Integration of subsystems into hierarchy	47
Process and mill models	42
Standardization	36
Man–machine interface	28
User-oriented programming	22
Self-diagnostics	19
Better algorithms and application of advanced theory	17
Impacts on management	3

the top of similar lists for years and no doubt will remain there, because accurate and reliable information on the states of the processes to be controlled is essential for good control. However, an important feature in Table 8 is the need for better process and mill models, especially those concerned with cost and productivity. There is also a need for better methods of integrating subsystems into hierarchical structures. These are necessary for building the upper levels of the hierarchy, i.e. production-planning and coordination systems, as depicted in Figure 3 (Uronen and Williams 1978). The production management (or area control) level must take care of all handling of material, from the purchase and transport of raw materials to the shipment and inventory of final products. A detailed discussion of the tasks at the various levels of such a hierarchy can be found in Uronen and Williams (1978).

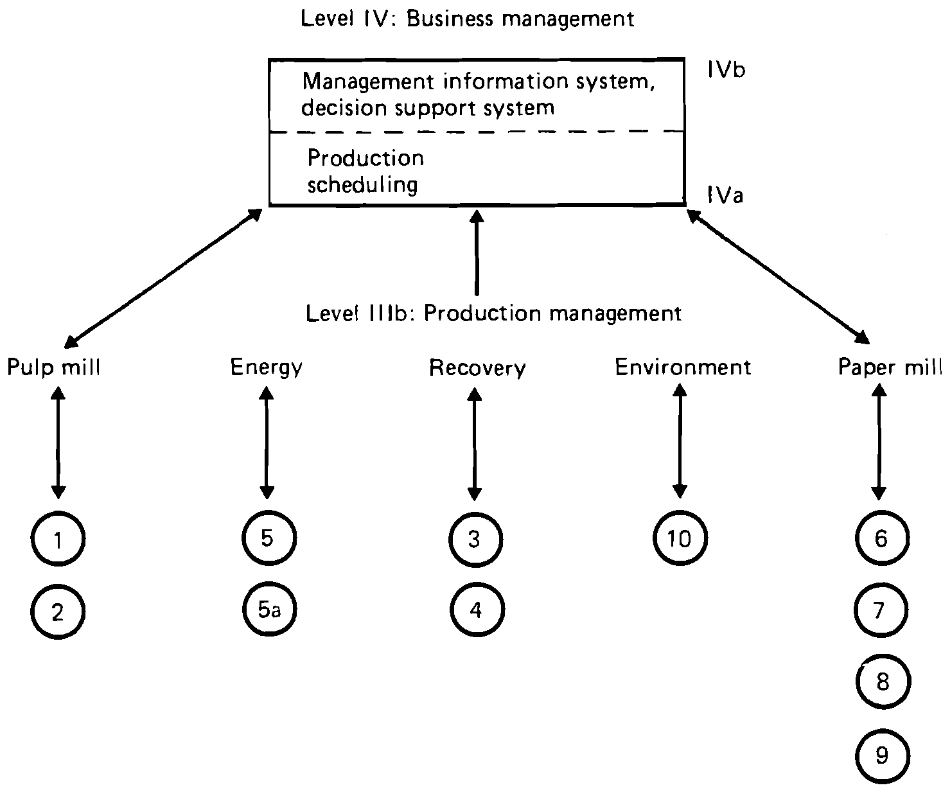

FIGURE 3 Process control hierarchy in an integrated paper mill. Levels I, II, and IIIa comprise: 1, woodyard, Kamyr, washing and screening; 2, bleaching, bleach chemical preparation; 3, evaporators, recovery boiler; 4, causticization and lime kiln; 5, power boiler, turbine generator, water treatment; 5a, purchased power; 6, additives, stock preparations; 7, on-machine processes; 8, roll handling and finishing; 9, laboratory; 10, wastewater treatments, special measurements, monitoring and alarms. Level IIIb comprises area control, detailed scheduling, coordination, quality control, optimization. Level IV comprises management information, production planning, decision support.

In this connection the opinions of the users about existing systems and some new trends were also examined. Tables 9 and 10 present the results. From Table 9 we can see that the users are quite happy with their existing process control systems. At the same time about half of the companies feel that their higher-level systems, including energy management systems, are not functioning satisfactorily. This is also an expected result, because the majority of experiences stem from the process control systems. This implies that the users are now aware of the possibilities and benefits that higher-level systems can provide.

Based on the results of Table 10, it may be said that the newer the idea the less confidence there is in its usefulness. The trend is obvious: Group A systems are important, Group B is useful, and Group C seems too theoretical so far.

TABLE 9 Users' opinions about existing systems.

System	Very good (%)	Satisfactory (%)	Unsatisfactory (%)
Process control	38	56	6
Production planning and coordination	5	74	21
Energy management	0	40	60
Tactical planning	8	38	54
Strategic planning	6	50	44
Management information	9	48	43

TABLE 10 Users' opinions about different systems.

System	Important (%)	Useful (%)	Not useful (%)
Group A (systems in use)			
Computerized process control	86	14	0
Computerized production planning	43	57	0
Computerized order handling	50	47	3
Computerized quality control	35	59	6
Computerized energy management	70	27	3
Group B (systems in exploratory phase)			
Computerized coordination system	38	47	15
Real-time management information system (MIS)	33	50	17
Hierarchical mill-wide information and control system	26	52	22
Combination of MIS and production control system	27	60	13
Group C (future systems)			
Decision support system (DSS)	14	57	29
Fully automated production	0	27	73
Electronic office	6	59	35
Personal computing tools	9	67	24

3 MANAGEMENT SYSTEMS

The use of computer-based systems in management assistance and data gathering and handling is in fact older than computerized process control. As described earlier, management systems tended to become separated from process control systems during the second generation of industrial computer systems, and this is still very much the situation. Most forest industry companies have quite large electronic data-processing (EDP) departments taking care of these management applications. This can be seen from Table 11, which shows the number of professionals in EDP departments and in process control departments in the companies in this study.

There is a large difference in staffing between the EDP and process control departments. Of the companies that answered, 29% do not have any professional engineers specializing in process control. This lack of professionally trained people will become a very serious problem in the building of integrated systems for the mills. It is also a demanding task of education and training at universities. This problem has already been noted by Bialkowski (1981) in Canada.

TABLE 11 Number of professionals in different application areas.

Number of professionals	EDP departments (percentage of answers)	Process control departments (percentage of answers)
<5	27	65
5–20	48	29
>20	25	6
Average	31	5

There have been several studies concerning the extent of use and users' opinions of corporate modeling and other management systems in industry (Naylor and Schauland 1976). No such study specifically covering the forest industry has been published. Therefore, it was felt important to examine the existing applications, users' experiences, benefits and drawbacks, and methods used in applications in the pulp and paper industry. Tables 12–16 summarize the results. Altogether 247 applications were reported, most of them in budgeting, inventory control, wood procurement, and transportation. Most users felt that these systems were important and useful. Further it may be noted that the applications in financial analyses and forecasts, investment analysis, profit planning, and forest management are quite well used. There seems to be some scepticism concerning the usefulness of management information systems and project management and control systems.

Applications such as resource allocation and plant location have not gained much ground among pulp and paper companies, although these applications have been well studied and documented. Table 13 shows that linear programming, simulation, and inventory theory are clearly the methods applied most. This result supports the findings of Naylor and Schauland (1976).

TABLE 12 Users' opinions about different computer-based systems in management applications.

System	Percentage of companies that use system	Important (%)	Useful (%)	Not useful (%)
Budgeting	75	81	19	0
Inventory control	75	59	37	4
Wood procurement, inventory, and transport	53	74	26	0
Profit planning	50	50	44	6
Financial analyses and forecasts	47	53	47	0
Project management and control	47	29	53	18
Investment analysis	44	56	38	6
Forest management	39	64	29	7
Management information systems	39	29	71	0
Marketing planning	33	42	42	16
Long-term forecasts	33	25	67	8
Corporate modeling	31	45	45	10
Transport planning	25	33	56	11
Purchasing planning	25	33	56	11
Risk analysis	19	14	58	28
Resource allocation	19	43	57	0
Plant location	14	45	45	10
Planning of R&D	11	0	25	75
Organization planning	6	0	0	100

TABLE 13 Methods used in management systems.

Method	Percentage of companies that use method
Linear programming	67
Simulation	44
Inventory theory	36
Program evaluation and review technique (PERT) or critical path method (CPM)	31
Time-series analysis	28
Exponential smoothing	28
Stochastic modeling	25
Deterministic modeling	22
Integer linear programming	19
Optimal control theory	17
Box–Jenkins method	14
Other forecasting method	11
Heuristics	11
Multiobjective optimization	8
Nonlinear programming	6
Dynamic programming	3
Goal programming	3
Network theory	3
Logistics	3

According to Table 14, management applications should be easy to use and have good reporting and simulation possibilities. They should use high-level programming languages and should work interactively with the user. The use of graphics does not seem to be very important.

Benefits of management applications (Table 15) that cannot be estimated in monetary terms, like more effective planning, better decision making, and more timely information, outweigh the benefits from cost savings and optimized inventory. The most serious drawbacks and barriers to spreading these systems further seem to be the development costs, long development time, lack of necessary data and models, and questions of personnel (training and attitudes), as shown in Table 16. Minor problems are updating and maintenance of the system, once installed. On the other hand, hardware reliability and running costs seem to present no problems.

The use of outside consultants is very common: in 70% of the cases outside consultants were used in developing the above-mentioned applications. In 55% of the cases the applications were purchased, the share of own development by the user being only 45%. When asked about current work in this area about 38% of the companies said that they were developing new applications; another 38% were developing new algorithms and models, and 24% had no active development work.

TABLE 14 Important features of management applications.

Feature	Percentage of answers
Easy to use and modify	70
Effective reporting	53
Simulation possibilities	47
Interactive operation	47
Sensitivity analysis	42
High-level programming language	39
Effective data-base functions	33
Graphics	30
Network communications	22

TABLE 15 Benefits of management applications.

Benefit	Percentage of answers
More effective planning	53
Cost savings	50
Better decision making	50
More timely information	42
More accurate forecasts	42
Better understanding of business	39
Evaluation of policy alternatives	33
Optimized inventory	31
Better goal setting	25
Confirmation of other analyses	17

TABLE 16 Drawbacks of management applications.

Drawback	Percentage of answers
Development costs	61
Long time to develop	53
Lack of necessary data	53
Training and education	44
Lack of special personnel	42
Attitudes	39
Updating and maintenance	33
Lack of models and algorithms	28
Lack of flexibility	28
Software difficulties	25
Poor documentation	14
Running costs	11
Unreliable hardware	3

4 INTEGRATION OF SYSTEMS

Since World War II the size of enterprises and organizations has grown rapidly. The effective management and control of large systems is difficult because, among other things, the formulation of comprehensive models and objectives is very complicated. The large size makes communication, data transfer, and the normal techniques of model solving and optimization very slow and impractical.

Further, corporations and their operations are becoming more and more dependent on exogenous factors such as customers, competition, availability of capital, governmental policies and regulations, interest groups, energy, and the labor market. Fast and reliable information systems in a corporation are essential. Several types of management information system (MIS) have been developed and applied (Golemanov 1981) but, as shown by the responses to the questionnaire, the users' experiences so far are not wholeheartedly positive.

Owing to better reliability and for economic reasons, there is now a general trend toward decentralized decision making, distributed computation and control, and hierarchical structures in large-scale, complex systems such as integrated paper mill corporations. This is leading to integration of control, information, and management systems according to hierarchical organizational and functional principles. Today, microcomputers and other distributed hardware make it technically feasible.

The general potential benefits and advantages achieved by using such hierarchical systems are (Leiviskä *et al.* 1980):

- Easier integration of all functions and better adaptability to existing organizations (most of which are hierarchical by nature).
- Flexibility and reliability.
- Better utilization of resources, such as the data-processing capability of individual subsystems. Then the distribution of functions, control tasks, and responsibilities between different levels of the hierarchy is a key planning factor.
- Reduction of complexity and, thus, simplification of the solution process.

- Greater ease in coping with uncertainties: in a decentralized hierarchy the decisions at different levels are made at different times and thus the data at lower levels could be uncertain when higher-level decisions are made. In a centralized system all decisions should be made at the same time and thus earlier than in a decentralized hierarchy at the lower levels.
- The limited decision-making capabilities of an individual are extended.
- Subsystems can be geographically far apart and have limited communication with each other.
- There will always be costs, delays, and errors when transmitting information. The distributed structure and decentralized decision making will minimize them.
- In the existing system there may be local autonomy created by the subsystems and/or privacy of information. These features can be included in and handled by the hierarchical structure.
- The development of distributed hardware and data-bus techniques (Heikkilä and Nikkilä 1980) has made integrated control, information, and management systems attractive to build and operate, both technically and economically.

In specifying and planning this kind of integrated hierarchical system there is a lot of research and development work, especially in the generalities and methodology connected with the planning, operation, and updating of the systems. The conceptualization, theory, and general advantages of hierarchical structure have been widely studied in recent years (Mesarovic *et al.* 1970, Athans 1974, 1978, Findeisen 1978, Findeisen *et al.* 1981). Applications for such systems already exist, for example in the steel industry (Miyazaki *et al.* 1978) and in the pulp and paper industry (Eriksson 1978, Uronen and Williams 1978, Peterson and Rückert 1978), but extensive implementation of the integrated system concept is just beginning. Therefore, the structuring, standardizing, and methodological principles are of the utmost importance. There are several major factors and changes, especially in the pulp and paper industry, that demand and favor the use and development of such integrated systems. Some examples are given here:

- A major part (about 80%) of production will be run outside the normal day shift, when top management is not on-site; therefore, the operators and other shift personnel need a suitable set of tools to help them make reliable and accurate decisions while operating the mill and planning short-term actions. This information must be stored and later used as an historical data base for checking and longer-term planning.
- Mills are becoming more and more complex (closed mill technology, larger units) and integrated (energy network, chemicals circulation, environmental protection).
- Economic factors (cost and efficiency) and productivity are very important today. This development will also mean that plant optimization will change from technological or process optimization to economic optimization. Thus, the dimensions and complexity of the problem of obtaining up-to-date cost and efficiency data will increase.
- New developments in microelectronics and other, related technologies have created new possibilities. The use of computer technology in the pulp and paper industry has reached a certain maturity and the general attitudes toward it are positive.

Most of the computerized unit process control systems in the pulp and paper industry have been profitable and successful investments (Keyes 1975), resulting in remarkable gains in terms of increased throughputs, higher yield, reduced consumption of raw materials and energy, and higher-quality products. This observation is supported by the results of the present study: most mills are satisfied with their existing process control systems.

At the higher levels of management the traditional real-time management information systems have not been as successful as expected. The results of the questionnaire clearly show this (Table 9). In parallel with real-time management information systems, decision support systems (DSS) have been introduced to help higher levels of management in industry and business (Fick and Sprague 1980). The decision support system is a new tool for decision makers and is just beginning to be accepted by industry. Its most important features are as follows:

- The system forms an effective and interactive link between the computer (data) and the decision maker (user).
- The system helps managers in making ill-defined, nonstructured decisions, where explicit and "standard" solutions obtained by algorithmic or other, similar means are not possible.
- The system will support human judgments and decisions.

These new possibilities at all levels of industrial organizations, from instrumentation to top management, have stimulated much discussion about the integration of all of these systems into a hierarchy using distributed hardware and real-time network communications (Williams 1978, 1980, Alsholm and Haglund 1977, Eriksson 1978, Hübner 1979, Fowler 1980, Haglund and Alsholm 1980, Uronen 1981, Golemanov 1981).

The development and implementation of this kind of total hierarchy is a long-term project demanding huge investments and planning resources, but the theoretical and technological know-how to build these systems is available. The users' opinions and needs concerning the usefulness and application of these systems must be paid the highest attention to avoid the risk of the vendors of computer technology and systems dictating the direction of progress. The most critical and important questions are as follows. How much integration should be recommended and how much does it depend on local circumstances? Is the integration of management systems with process control systems useful or advisable? How should one combine the different systems and the distributions of tasks, functions, and data bases? What are the effects of this kind of system on the organization and what are the most important topics for research and development in this area? These questions were included as a central part of the questionnaire and the responses can be analyzed in detail.

The starting point is the current organization of data-processing activities (responsible for management systems) and process control activities inside the companies. The questionnaire revealed that the existing organizations prefer to keep process control systems and data-processing systems separate at all levels of organization. The majority for separate organizations was 92% to 8% at mill level, 79% to 21% at division level, and 92% to 8% at corporate level.

From Table 17 we see that in the present situation the decentralized, mill-level organization for the process control area is predominant, with some degree of coordination at

TABLE 17 Organization of the data-processing and process control work in companies.

Type of organization	Percentage of companies using process control systems	Percentage of companies using data-processing systems
Decentralized, mill-level organization	53	24
Coordinated at division level	6	8
Division-level organization	9	8
Coordinated at corporate level	21	19
Centralized, corporate-level organization	11	41

the level of the corporation or division. This is quite reasonable and an expected result because the technological processes and needs may vary from mill to mill. For standardization and coordination purposes a small corporate staff is available. In the data-processing area the centralized organizations are more common: 41% of the companies that answered have corporate-level organization, 19% have corporate-level coordination, and 24% have a decentralized, mill-level organization.

This result was also expected: the character of data processing is more general and more closely related to corporate-level operations. Those in favor of more centralization stated that the most important benefits are common documentation, better coordination, technology transfer, staff training, lower costs, and promotion of information at the mill level. However, when the companies were asked about organization and integration of the systems in the future, they expressed a different opinion, as shown in Table 18.

The trend here is clear: more integration, especially at mill level, is an important need. There are some significant factors opposing this development: different types of work have different aspects and time horizons; each mill has its own technical preferences and management style; the data-processing people and process control people do not understand each other's work and problems, thereby showing that there is also a problem of training and education.

The idea of building multilevel (three to five levels) hierarchical integrated systems, starting from process control and including the management information system and similar functions at a high level, has been widely discussed (Tinnis 1974, Alsholm and Haglund 1977, Uronen and Williams 1978, Uronen 1980a, b, Leiviskä and Uronen 1980, Golemanov 1981). Table 19 shows the opinions of the respondents.

From Table 19 we can conclude that there is remarkable interest in integrated systems, especially at mill level. The integration of systems by using data-base technology

TABLE 18 Integration of process control systems and data-processing systems in the future.

Type of organization	Yes (%)	No (%)
Integration at mill level?	79	21
Integration at division level?	52	48
Integration at corporate level?	39	61

TABLE 19 Opinions about integrated hierarchical systems.

(a) Type of hierarchy	Useful (%)	Not important (%)
Mill level	97	3
Division level	82	18
Corporate level	50	50

(b) Benefit	Percentage of answers
Better decision making	78
Better coordination	67
Better productivity control	64
Cost savings	61
More accurate and timely data	61
Easier planning	56
Standardization	44
Personnel savings	22

(c) Ongoing development work

System to be developed	Percentage of answers
Hierarchy at mill level	44
Hierarchy at division level	25
Hierarchy at corporate level	22

(d) How the management systems and process control systems should be combined.

Integration	Percentage of answers
None	8
Same data bases	44
Real-time communications	39
Full integration	9

(e) Future development work

Activity planned	Percentage of answers
Expansion of existing MIS	30
Develop DSS	27
Start to build MIS	20
Integration of MIS and production control	18
None	5

permits the use of common data bases in real-time communication, which seems to be the most feasible solution for the future.

Finally, the recommendations and suggestions for important research topics were explored. Table 20 indicates the answers. The topics suggested indicate quite clearly the following important problem areas: economics of automation and data-processing systems; organizational effects; and needs for standardization and easier programming systems. Longer-term topics are DSS and fully automated production.

TABLE 20 Future research topics suggested.

Topic	Percentage of answers
Economics of the system	39
Distribution of decision making and its effects on MIS	39
Mill productivity models	36
Production-scheduling and coordination algorithms	36
Nonprocedural programming languages	33
Standardization	33
DSS in forest industry	28
Fully automated mills	19
Corporate-level hierarchy	14

5 CONCLUSIONS

There is clearly remarkable interest, as well as progress, in the integration of control, information, and planning systems at various levels in the pulp and paper industry. To a large extent, this has been encouraged by the new generation of distributed hardware, which permits a greater flexibility in the construction of integrated hierarchical systems. The application of the new generation of these integrated information systems is now at its early stages, without any standards or "packaged" solutions. Therefore, this would be an appropriate time to try to develop guidelines and standards for these systems and their usage, according to the opinions and wishes of the users, before the market becomes too much influenced by the hardware and by the vendors of these systems, as has been the case sometimes in the short history of computers in industry. Some critical questions to be thoroughly studied when developing these systems are:

- How much complexity in the hierarchical structure and in the integration of the systems is reasonable at various levels of organization?
- What is the optimum level of automation and how much does it depend on local circumstances, mill or company size, product mix, etc.?
- How much standardization and how many general packages or modules is it feasible to develop for these kinds of integrated systems?

Economic payoff studies of different scenarios of integrated systems in a typical mill using actual data would be important. What new models and algorithms are needed in these systems? How applicable are existing models and algorithms? What are the effects of these systems on organizations and on education of people at all levels of organization? From the results of this study it seems quite obvious that at mill level the integration is feasible and advantageous. Most mills are planning to implement this kind of system in the near future. The completion of this integration at division and corporate levels is not so certain and many companies do not see it as necessary. Therefore, a total system, like the one depicted in Figure 4, might be a general scheme for corporation-wide system integration with the aid of three levels connected by data highways. In addition to these levels,

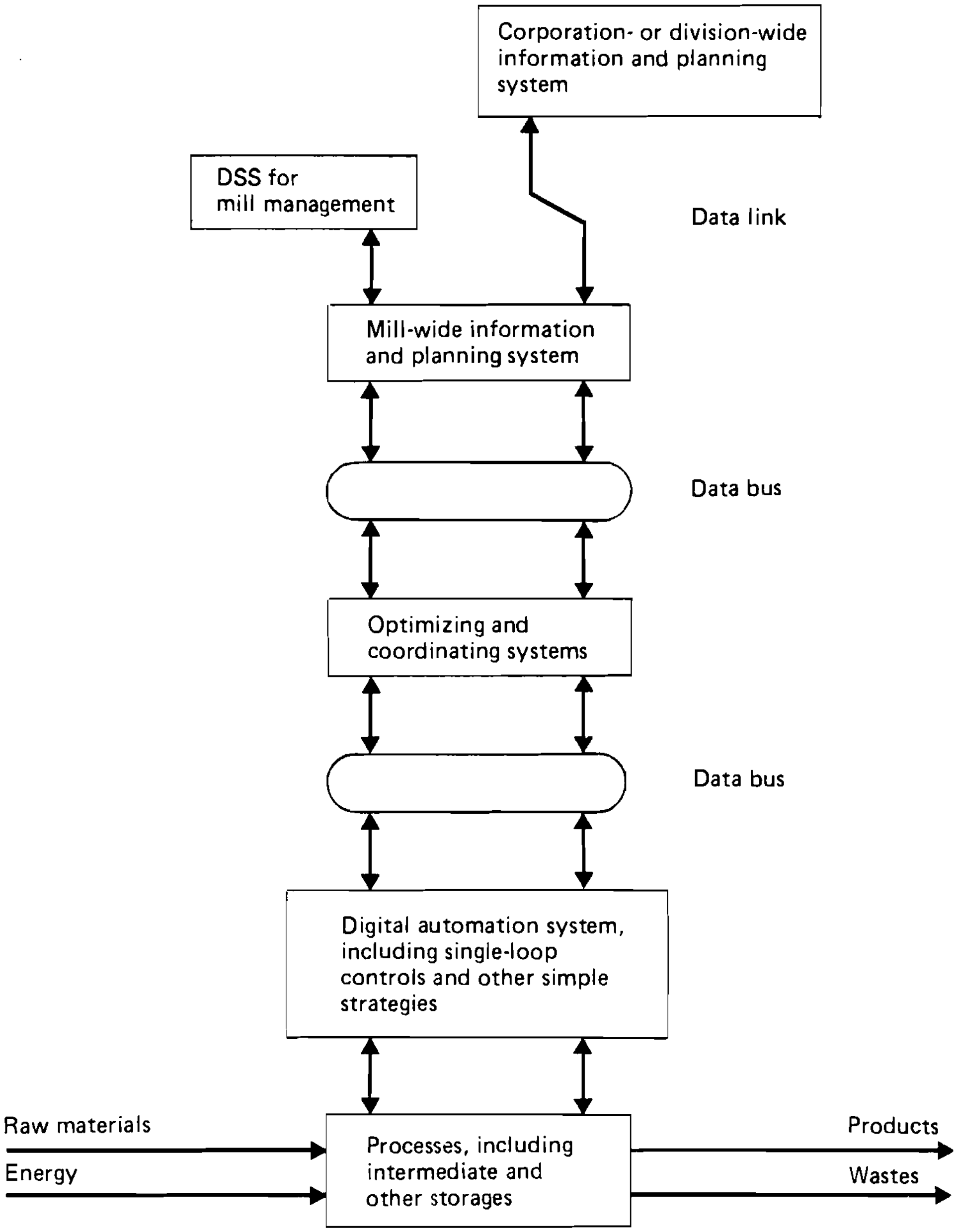

FIGURE 4 Proposed integrated system hierarchy.

a decision support system for mill management and a data link to division-wide and corporation-wide information systems are needed.

With this kind of development, and by use of digital instrumentation systems and other distributed hardware and effective video and other man–machine communications, traditional control rooms with many recorders, indicators, counters, and semigraphic process flow diagrams will be transformed, and thus also the work of personnel will change significantly. Another interesting new area of development is the company internal information system similar to those operated by some public companies. Such a system should handle the company's internal information and could be the first step forward in decision support systems. It is evident that the development will go in the direction of integrated information systems. This implies a higher level of automation. Already today we have the technical capabilities to realize fully automated production, where operators are only in one (or very few) control center(s). Hardware development seems to be far ahead of software development and there are no established solutions or standards for integrated systems. Another big problem area will be organizational and other man–machine effects. Development work in these areas must be encouraged, as was made clear from the results of this investigation.

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APPENDIX

QUESTIONNAIRE ON THE USE OF COMPUTER-BASED SYSTEMS: ANALYTICAL APPLICATIONS IN THE FOREST INDUSTRY

(Please type or use block capitals. Tick boxes and/or delete where applicable.)

A. General

1. Name of the company:

Main products:

Annual capacities:

Annual turnover:

<100 M$	☐
100–500 M$	☐
500–1000 M$	☐
>1000 M$	☐

Own forest lands:

None	☐
<100,000 ha	☐
>100,000 ha	☐

How many divisions? ___
How many mills? ___
How many mill locations? ___

2. Organization of systems-analytical work in your company.

	Process control systems	Data-processing and administrative systems	All systems combined
Centralized corporate organization	☐	☐	☐
Corporation-wide coordination	☐	☐	☐
Centralized organization inside divisions	☐	☐	☐

Division-wide coordination	☐	☐	☐
Decentralized (mill- or plant-level organization)	☐	☐	☐

Do you have plans to centralize this systems organization? Yes/No
If yes, or if you already have a centralized organization, can you specify some benefits that you see with the centralized systems organization?

3. Systems development work in your company.

Number of professionals in electronic data-processing (EDP) group: ___
Number of professionals in process control group: ___
Do you regularly use outside consultants? ___
Do you have R&D cooperation with:
  Consulting companies? ___
  Engineering companies? ___
  Universities? ___
  Research institutes? ___
  System vendors? ___
Have you bought most of your systems as ready products from the vendor? ___
How large, for example as a percentage, is your own development work? ___
Do you think that most "packages" available on the market need tailoring to your company? ___
Will this tailoring be made by you, by the vendor, or jointly? ___

4. Corporation-wide systems.

Do you think that process control systems and management and administrative systems (EDP) should be kept fully separated:
  (a) At corporate level? ___
  (b) At division level? ___
  (c) At mill level? ___
Reasons:

Do you think a hierarchical multilevel information and control system starting from process control and including the management information system (MIS) is useful and important:

(a) At corporate level? ___
(b) At division level? ___
(c) At mill level? ___

Benefits:

- Standardization ☐
- Common data base gives more accurate data, and faster ☐
- Cost savings ☐
- Personnel savings ☐
- Better decision making ☐
- Better coordination ☐
- Better productivity control ☐
- Easier planning ☐
- Other ☐

Weaknesses:

Are you building a corporation/division/mill-wide systems hierarchy in your company? ___

B. Process and Production Control Systems

1. The existing systems in your mills.

	Number	Package	Own development
Batch digester control	___	☐	☐
Continuous digester control	___	☐	☐
Bleach plant control	___	☐	☐
Washing and screening plant control	___	☐	☐
Pulp-drying machine control	___	☐	☐
Evaporator plant control	___	☐	☐
Recovery boiler control	___	☐	☐
Lime kiln and causticization control	___	☐	☐
Power boiler control	___	☐	☐
Thermomechanical pulping plant control	___	☐	☐
Grinder control	___	☐	☐
Stock preparation control	___	☐	☐
Paper machine control systems	___	☐	☐
Coater control systems	___	☐	☐

Roll-handling systems	___	☐	☐
Quality monitoring and control	___	☐	☐
Inventory system	___	☐	☐
Trimming and scheduling system	___	☐	☐
Energy management system	___	☐	☐
Order-handling system	___	☐	☐
Environmental monitoring system	___	☐	☐
Production-planning system	___	☐	☐
Production coordination and control system	___	☐	☐

2. *What new unit process control systems do you expect and plan to install during the next five years in your mills?*

3. *Are you planning to implement a production-planning and coordination system in the near future?* Yes/No

If yes, what are the main benefits you see to be achieved with it?

- Better use of equipment and capacity ☐
- Increased production ☐
- Decreased losses and risks ☐
- Better decision making ☐
- More accurate and timely information ☐
- Better cost and effectiveness control ☐
- Easier and more flexible planning ☐
- Personnel savings ☐
- Increased safety in operation ☐
- Other (please specify)

4. *If you think that a computer-based production-planning and coordination system is not useful, what are your main arguments?*

- High costs ☐
- Difficult and complex programming ☐
- Lack of models and algorithms ☐
- Unreliable and incompatible equipment ☐
- Training and education of personnel ☐
- The benefits are marginal only ☐
- Other (please specify)

5. *If you already have a computer-based corporation- or mill-wide production-planning system, what are your experiences?*

The system was built separately without any or with very little connection to the process control system ☐
The system was built by using as much as possible of the process control system ☐

The main benefits are:

Higher production ☐
Easier and more flexible planning ☐
Decreased losses and disturbances ☐
Personnel savings ☐
Better information and decision making ☐
Other (please specify)

The main problems are:

Costs ☐
Training ☐
Updating of the system ☐
Maintenance ☐
Other (please specify)

6. *Needs for R&D in this area (mark the three most obvious):*

New and better sensors ☐
Development of better process and mill models ☐
Development of more efficient control algorithms and increased use of advanced control theory ☐
User-oriented programming ☐
Self-diagnostics of the systems ☐
Standardization of communication and programming ☐
Better man–machine interface ☐
Methods for integrating the subsystems into a hierarchy ☐
Other (please specify)

7. *How do you maintain and update your systems in this area?*

"Babysitter" – the vendor on-site	☐
Own maintenance department	☐
Emergency repairs only	☐

8. *How do you train and educate your people in using the computer-based systems?*

No organized training inside the company	☐
Company-organized seminars, courses, tutorials, etc.	☐
Active participation in outside courses, etc.	☐
Special programs designed and organized by consultants and institutes	☐

9. *How do you rate your existing systems in the following areas?*

	Very good	Satisfactory	Not satisfactory
Process control systems	☐	☐	☐
Production planning and coordination	☐	☐	☐
Energy management	☐	☐	☐
Tactical planning	☐	☐	☐
Strategic planning	☐	☐	☐
Management information systems	☐	☐	☐

10. *What is your opinion of the following systems?*

	Important	Useful	Not useful
Computerized process control	☐	☐	☐
Computerized production planning	☐	☐	☐
Computerized order handling	☐	☐	☐
Computerized quality control	☐	☐	☐
Computerized energy management	☐	☐	☐
System for coordination of different departments	☐	☐	☐
Real-time management information system	☐	☐	☐
Hierarchical, multilevel (3–4 levels), corporation- or mill-wide information and control system	☐	☐	☐
Combination of management information and production control systems	☐	☐	☐

Use of computers at the highest level of management (decision support systems)	☐	☐	☐
Idea of totally automated production in the forest industry	☐	☐	☐
Electronic office	☐	☐	☐
Personal computing tools	☐	☐	☐

C. **Management Systems**

1. *Which of the following computer-based applications of systems analysis are used in your company and how do you rate them?*

	Important	Useful	Not useful
Corporate modeling	☐	☐	☐
Plant location	☐	☐	☐
Resource (= forest) management	☐	☐	☐
Budgeting	☐	☐	☐
Marketing planning	☐	☐	☐
Investment analysis	☐	☐	☐
Profit planning	☐	☐	☐
Long-term forecasts	☐	☐	☐
Financial analyses and forecasts	☐	☐	☐
Inventory control	☐	☐	☐
Project management and control	☐	☐	☐
Planning of transportation	☐	☐	☐
Organizational planning	☐	☐	☐
Risk analysis	☐	☐	☐
Planning of R&D	☐	☐	☐
Purchasing planning	☐	☐	☐
Management information system	☐	☐	☐
Resource allocation	☐	☐	☐
Wood procurement, inventory, and transport	☐	☐	☐

2. *Which of the following systems-analytical tools and methods are used in your company in the above systems?*

Linear programming	☐
Integer linear programming	☐
Nonlinear programming	☐
Dynamic programming	☐
Multiobjective optimization	☐
Goal programming	☐

- Deterministic models ☐
- Stochastic models ☐
- Simulation ☐
- Gaming ☐
- Heuristics ☐
- PERT or CPM ☐
- Inventory theory ☐
- Network theory ☐
- Optimal control theory ☐
- Time-series analysis ☐
- Box–Jenkins method ☐
- Exponential smoothing ☐
- Some other forecasting method ☐
- Other (please specify)

3. *Important features of the above applications:*

- Easy to use and modify ☐
- Effective reporting ☐
- Effective data-base management and utilization ☐
- Graphics ☐
- Sensitivity analysis ☐
- Effective simulation possibilities ☐
- Interactive operation ☐
- High-level programming language ☐
- Network communications ☐

4. *Benefits of the applications:*

- Better understanding of business ☐
- More accurate forecasts ☐
- Cost savings ☐
- More timely information ☐
- More effective planning ☐
- Optimized inventory ☐
- Evaluation of policy alternatives ☐
- Better decision making ☐
- Better goal setting ☐
- Confirmation of other analyses ☐

5. *Drawbacks and reasons for the gap between theory and practice in the use of management science and management information systems:*

Poor documentation ☐
Lack of necessary data ☐
Lack of necessary models and algorithms ☐
Unreliable hardware ☐
Development costs ☐
Long time to develop ☐
Training and education ☐
Lack of special personnel ☐
Running costs ☐
Lack of flexibility ☐
Software difficulties ☐
Output format design ☐
Attitudes ☐
Updating and maintenance ☐

6. *Do you use outside consultants, e.g. universities, software houses, computing centers, in the further development of your systems?* Yes/No

7. *To what extent are the above applications your own development and to what extent are they purchased programs or packages?*

Totally own development ☐
Mainly own development ☐
Mainly purchased products ☐
Totally purchased products ☐

8. *Ongoing R&D work in this area in your company:*

New applications ☐
New models ☐
New programs ☐
None ☐

9. *To what extent do you think these systems should be combined with the process control and production-planning systems?*

Not at all ☐
Same data bases ☐
Real-time communications ☐
Full integration ☐

10. In the near future are you:

Starting to build management information systems? ☐
Expanding your existing management information system? ☐
Starting to study and develop decision support systems? ☐
Not developing new applications? ☐
Integrating the management systems with the production-planning and control system? ☐

11. Recommendations for future R&D:

Use of the decision support system idea in the forest industry ☐
Corporation-wide hierarchy ☐
Production-scheduling and coordination algorithms ☐
Distribution of decision making (corporate versus mills) and its effects on the management information systems ☐
Economic payoff studies of different systems ☐
Man–machine communication (nonprocedural languages) ☐
Mill productivity models ☐
Fully automated mills ☐
Standardization ☐
Other (please specify)

12. Are you interested in the IIASA task force meeting planned for May 1981, where the results and findings of this questionnaire will be discussed? Yes/No

13. Other comments and suggestions for IIASA:

14. Name and address of the contact person in your company:

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