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PRESENT STATUS AND FUTURE NEEDS: THE VIEW FROM JAPANESE INDUSTRY

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Abstract. The current environment in Japanese industry is described. Changes in demographics and lifestyles with resultant economic repercussions are studied. Statistics on the current state of Japanese process control are presented. Then, a suitable strategy that corporations should adopt for coping with these changes is discussed with attention given to required technology. Future research needs are identified.

Keywords. Process Control; production systems; Computer Integrated Manufacturing; Intelligent Operation Systems.

INTRODUCTION

Plant automation has progressed steadily, supported by the development of computer engineering. PSE (Process Systems Engineering) has also played a certain role in this progress. To assume still more roles, however, it is important to recognize correctly the state of current industries and to grasp precisely what is really required for the present and future.

In this paper, the environment surrounding Japanese industries is analyzed, and corporate strategies are recommended. Appropriate responses to those requirements in the field of PSE are studied.

ENVIRONMENT SURROUNDING JAPANESE INDUSTRIES

When envisioning future industrial production systems, it is necessary to understand the social environment in which we are now situated. There are three features in the Japanese social environment that affect production activities.

First, quality of life has become more important. At one time, Japanese people worked recklessly, and were even called "workaholics." Nowadays, however, the general way of thinking in Japan is changing, not to mention that of the younger generation. Most people consider themselves members of the middle-class and place a high priority on enjoying life. Thus, consumption is diversified, and consumers are demanding more and more products that display originality.

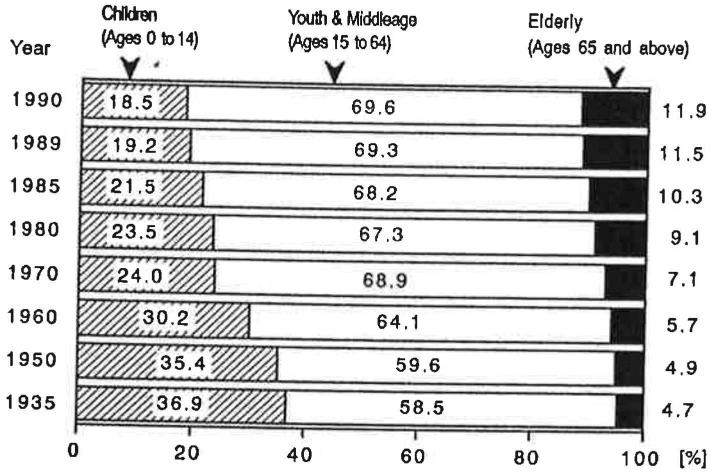


Fig.1 Change in population ratio (Source: Mainichi Newspaper, May 5,1990)

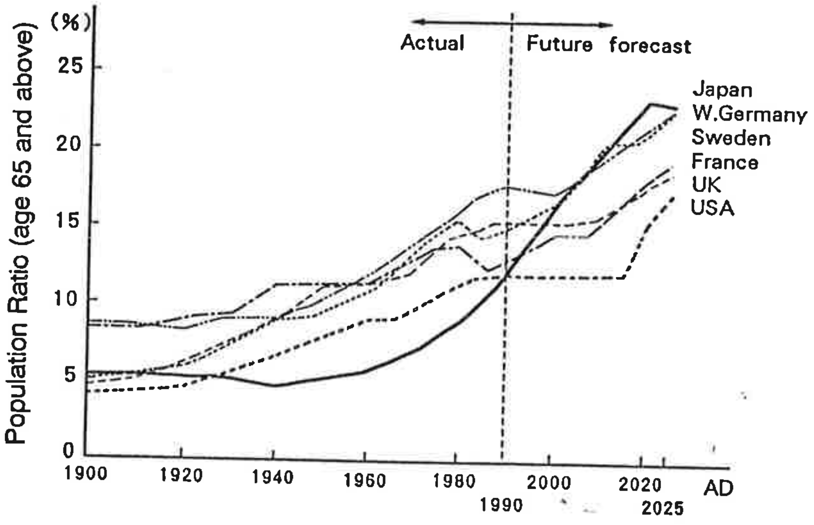


Fig.2 Population ratio of the elderly in Japan
(Source: Mainichi Newspaper, April 10,1990)

Second, the population is aging, and there is a shortage of young workers. Birth rates have been falling. For instance, the percentage of children below 15 years of age was 21.5% in 1985, and has fallen to 18.5% in 1990. In addition, with improvements in living standards, young workers have come to dislike entering manufacturing industries, where working conditions are rigorous, causing labor shortages in many industries. This problem may become more serious in the future (Figs. 1 and 2).

Third is developments in computer technology. This made possible various kinds of technological innovation, changed our way of living, and exerted considerable influence upon production activities.

CHANGE IN JAPANESE CHEMICAL INDUSTRIES

Fine-Chemical-Oriented Products

After World War II, the Japanese economy expanded by directing heavy industries. It can be said that chemical industries also attempted to make their plants large-scaled and continuous, following the trend of the times. However, with the first oil shock in 1973 as a turning point, no more high-economy growth could be expected, and the trend has changed to low-growth. With that change, high-value-added products are becoming the target of production. Further, connected with high-tech-related advanced technology, the importance of fine-chemical industries is being emphasized much more (Fig. 3). In this field, however, there are many

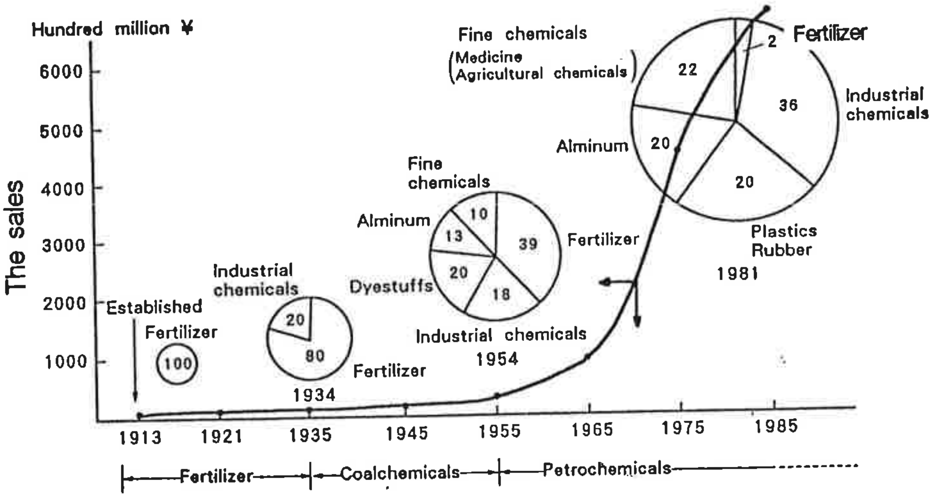
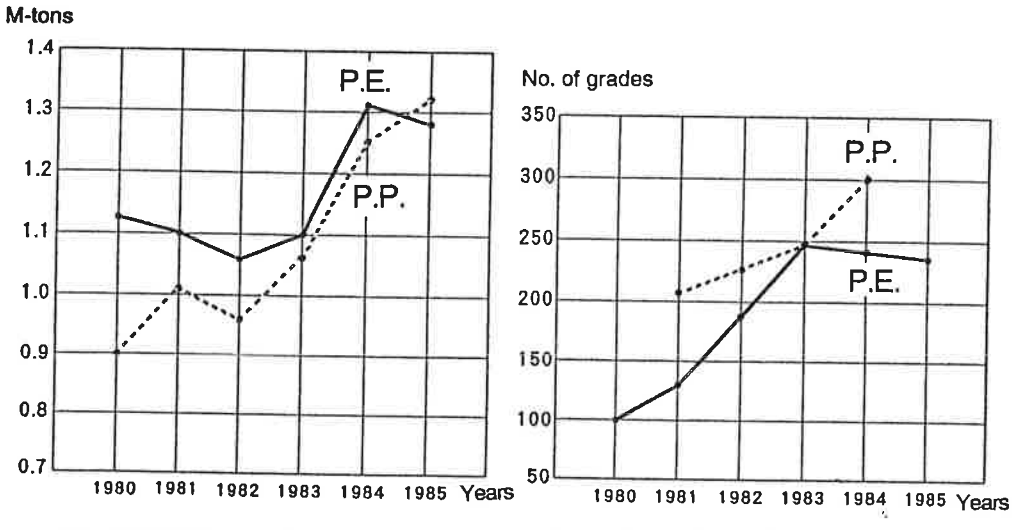


Fig.3 The change of chemical industries

products that still have high import ratios. The construction of many laboratories in Japan by large, multinational chemical companies suggests that there is an ample market for such products in Japan.

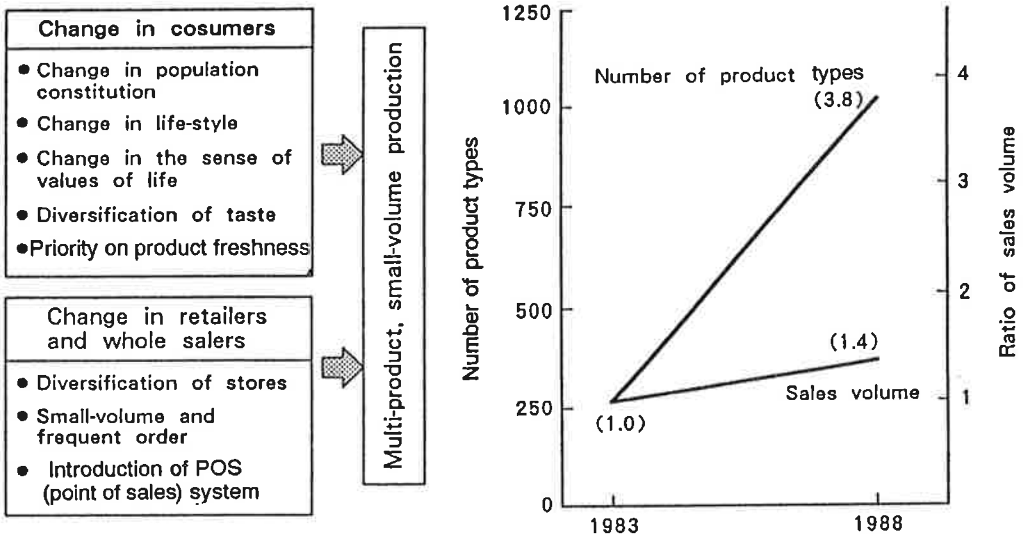
Diversified Requirements for Products

For instance, general-purpose polyolefines such as polyethylene and polypropylene, which were the centerpiece of Japanese petrochemical products, now cannot maintain predominance over imported products because of cost increases after two oil shocks and demand increases can no longer be expected as shown in Fig. 4-a (Tomura, 1988). Nevertheless, to preserve important positions in key materials, grade variation and product diversification have been attempted, aiming at product discrimination (Fig. 4-b). In addition, measures such as cost reduction and quality improvement have been taken. The number of product types has increased to several hundreds. And how to produce these many kinds of products economically by large-scale continuous plants while maintaining high quality has become the most essential task.



(a) Production volume (b) Number of product types

Fig.4 General-purpose polyolefines produced at a Japanese company (Tomura, 1988)



Structure of multi-product, small-volume production

Fig.5 Trend in number of product types and sales volume of frozen foods at a Japanese company (Doi, 1988)

Figure 5 (Doi, 1988) shows another example of this trend in the field of foodstuffs. As shown in the figure, the emergence of multiproduct, small-quantity production is apparent, resulting from changes in consumer lifestyle and sense of values, diversification of taste, and an increased priority on product freshness in addition to changes in distribution among retailers and wholesalers.

In both continuous and batch processes, CIM (Computer Integrated Manufacturing) is being promoted actively, aiming at safer and more stable operations, productivity improvement, quality improvement, energy conservation, and manpower reduction while realizing these objectives in an integrated form. Yet, as a matter of course, the extent and the nature of process requirements will differ depending on the products to be produced. The requirement for high quality and CIM is strong, especially in fine-chemical processes.

Conditions Inevitably Required in Future Processes

Flexibility in production and a nimble response to customers' demands are strongly required as indispensable capabilities for future processes. In order to design and operate such processes the following problems have to be resolved.

How to cope with increased inventories accompanying multiproduct production. Increases in product type require increased inventories to ensure a stable flow of products to customers. To decrease inventory, there is no production method other than the JIT (Just In Time) method, which increases the frequency of changeovers. Generally the changeover of plants generates losses in raw materials, products, energy, and labor. Thus the production cost increases in proportion to changeover frequency. There are two ways to reduce changeover cost. One is to reduce changeover time by modifying plant hardware or by introducing more advanced automation. The other is to reduce the sum of the costs necessary for maintenance of product inventories and the costs incurred by the changeover by introducing a highly capable scheduling system that can generate the optimal production schedule.

How to cope with handling diversified raw materials. There are many raw materials for fine-chemical products that require intricate handling and care because of their various forms and types. Especially, materials in the form of fine particles are difficult to handle because of their deliquescence and fluidity, obstructing the introduction of FA (Factory Automation). Therefore, pipeless plants are now attracting strong attention from many companies.

STRATEGY TO BE PURSUED BY COMPANIES

Within the above-mentioned environment surrounding Japanese society, especially Japanese chemical industries, the strategy that should be taken by companies can be expressed by four key phrases.

Production Information Integration

It is necessary to grasp production-related information in integrated form, from orders received to design to production to shipping to quality assurance, as represented by CIM, the current trend.

Hyperautomation

Thorough manpower reduction is by all means necessary, even though complete unmanned operation is impossible at present. To achieve manpower reduction, many tasks, such as operation integration and automation of maintenance and security, should be accomplished.

Cost Reduction

It is necessary to reduce production costs significantly by way of reducing inventory using JIT production, reducing losses due to recipe change accompanying multiproduct and small-quantity production.

Human Resource Recruitment

It became a crucial problem to recruit many able young workers, effected by making production environments attractive for younger employees. At the same time, it is still essential to train the personnel now employed so that they can cope with technology innovations.

Accompanying the integration of control rooms, it is required that many processes be monitored and controlled by one operator. That is, it is required that the operators be multitalented and highly skilled. Thus, extensive training becomes necessary.

APPLICATION OF ADVANCED CONTROL TECHNIQUES IN JAPAN

The Japan Electric Measuring Instrument Manufacturers' Association (JEMIMA) conducted a survey on the current status of process control systems, their needs, and future trends. The Association distributed and collected questionnaires from September—December, 1989, and published final results in March, 1990. Following are selected conclusions.

TABLE 1 Distribution of Questionnaires and Response Rate

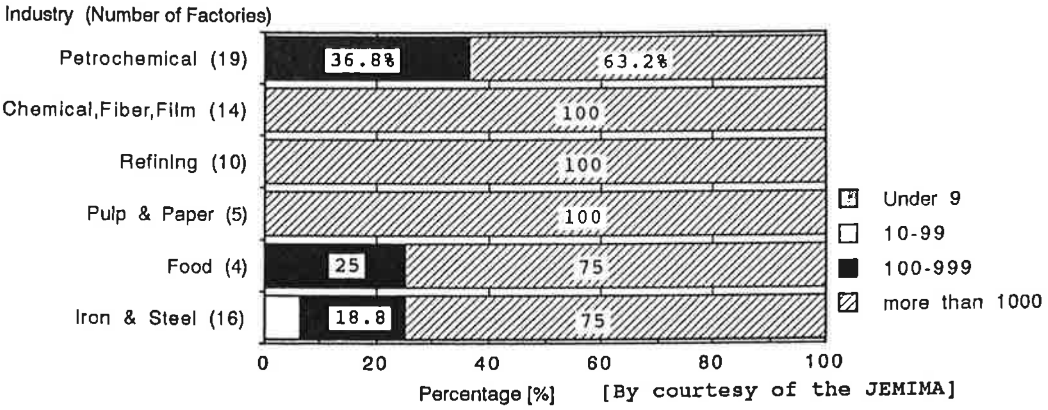
Industry	Number Distributed	Response	Response Rate
Iron and Metals	44	23	52.2%
Refining Petrochemical Foods Pulp and Paper	120	52	43.3
Power, Gas, Water Sewage, Heavy Industry Shipbuilding, Automotive	166	58	34.9
Total	330	133	40.3

Three hundred thirty questionnaires were distributed, with 138 responses, classified in Table 1. In the following sections, key results related to chemical processes are described; however, some results dealing with the iron and steel industry are added for comparison.

Number of Control Loops in Factory Site

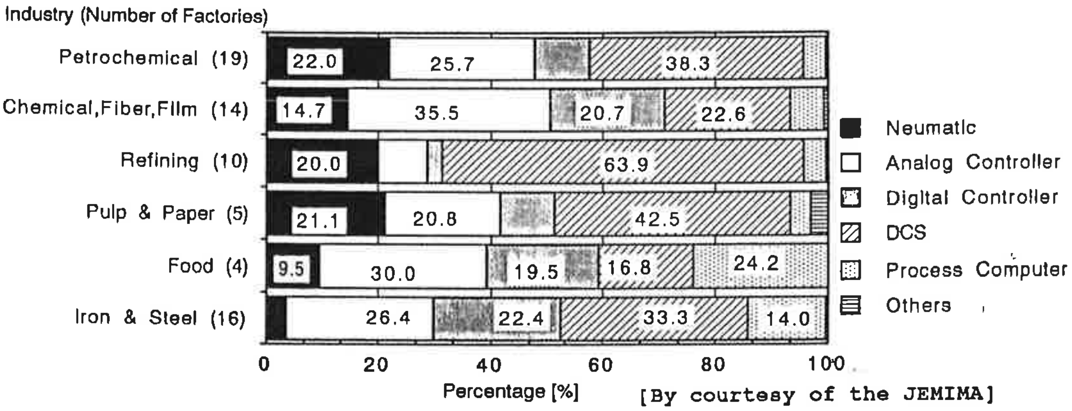
Table 2 shows that slightly more than 60% of factories responding have large-size plants, with more than 1000 control loops.

TABLE 2 Number of Control Loops



[By courtesy of the JEMIMA]

TABLE 3 Construction of Controllers



[By courtesy of the JEMIMA]

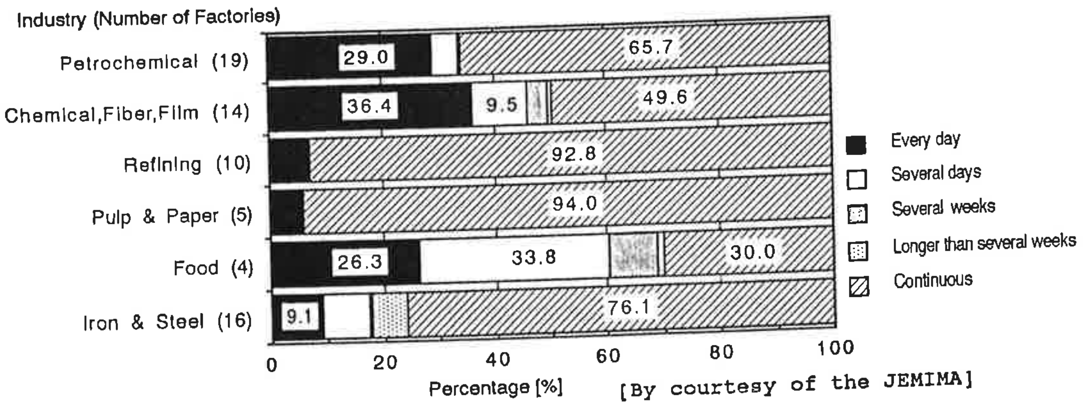
Construction of Control Systems

Table 3 indicates that in many factories, control systems are equipped mainly with analog controllers, digital controllers, and distributed control systems (DCS). Use of DCS is conspicuous in refineries, but the degree to which DCS is introduced does not necessarily depend on plant size.

Operation Mode

Table 4 shows the relation between modes of operation and control loops. A majority of the control loops are used for plants that are operated continuously. Most of the plants in the responding factories (73%) are continuous plants. Of the remaining plants, which are batch plants, 60% are operated batchwise with a 24-hour cycle time. The ratio of batch-type to continuous-type process has not changed over the past ten years. However, the demand for a good scheduling system has significantly increased.

TABLE 4 Operation Mode



[By courtesy of the JEMIMA]

Control Methods

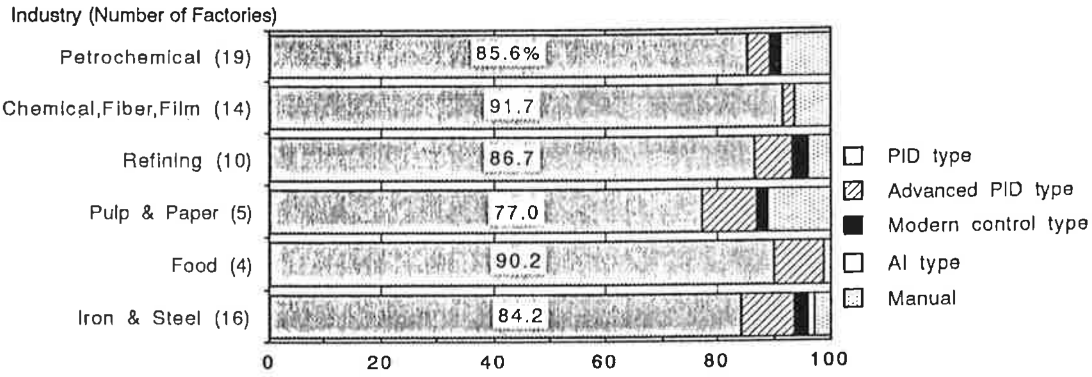
Table 5 shows types of control methods used in factories, with corresponding percentages.

The control methods are classified as follows:

- •PID type: On-off control, PID control, feed-forward control, sampling PI, etc.
- •Advanced-PID type: PID with decoupler, dead-time compensation, gain-scheduling, PID auto-tuning controller.

- •Modern control theory type: Optimum regulator, observer, Kalman filter, model-predictive control, adaptive control, H^∞ optimum control, optimization control.
- •AI type: Rule-based control, fuzzy control, neural network.

TABLE 5 Application of Control Methods



[By courtesy of the JEMIMA]

Table 5 indicates that more than 90% of control loops use PID-type or advanced-PID-type controls. Modern-control-theory and AI-type controls are not used very much. Among the loops controlled by PID, more than 80% are running satisfactorily, according to the report. The report also says that the less than 20% of loops remaining have some difficulties, such as dead time, mutual interaction, disturbance, and changes in process characteristics.

Application of Control Methods

The questionnaire asked about application, classifying responses in four categories:

A: Already applied.
B: Studied but not applied.
C: Under study and have possibility of applying.
D: No possibility of applying.

The results are displayed in percent in Fig. 6.

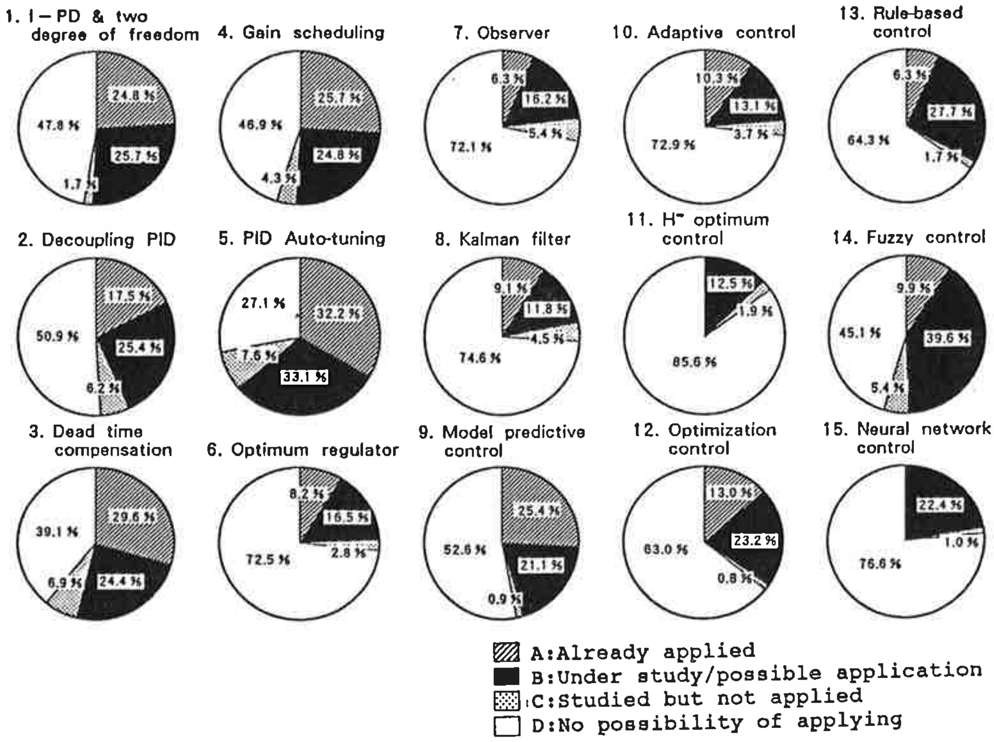


Fig.6 Application of control methods [By courtesy of the JEMIMA]

•Advanced-PID-type control (Nos. 1—5) is widely applied; on average; about 30% of responding factories replied that they had already used this type. Including those intending to apply, the figure rises above 50%.

•Model-predictive control is exceptionally widely-used among modern control techniques (Nos. 6—12). Slightly less than 26% of the factories have applied it. Including those intending to apply, the figure rises above 50%.

•Excluding H^{∞} optimum control and predictive control, the application of modern control theory is 10% or more. Even including those with studies in progress, the figure is at most 30%.

•Though AI type (Nos. 13 and 14) is applied in only 10% of responding factories, it has a high potential for being applied more widely in the future.

•Neural network (No. 15) and H^{∞} optimum control types have not been applied yet. Future trends should be watched.

Benefits of Application

Table 6 shows the expectations for these control techniques, selecting the top three responses for each technique.

•Advanced-PID-type control is at the stage of everyday application. The benefits of its application are expected as follows: a. Assurance of safe, stable process operation. b. Improvement of product quality. c. Conservation of manpower, automatic operation, and improvement of operability.

•Although the modern-control-theory type, as well as advanced-PID-type control, is expected to have benefits in terms of safe and stable operation, it is further expected to have benefits in terms of quality improvement and energy conservation. Increased familiarity with advanced techniques is listed as one of the benefits of modern control theory application.

•Expectations of AI are clearly defined. Emphasis is put on replacing humans in performing tasks and on reducing required manpower. Neural-network control is considered to be still under development, compared with rule-based control or fuzzy control. Many respondents think a central purpose of AI application is acquired familiarity with advanced techniques.

TABLE 6 Expectations for Control Techniques.

Benefits	1. I – PD & two degree of freedom	2. Decoupling PID	3. Dead time compensation	4. Gain scheduling	5. PID auto-tuning	6. Optimum regulator	7. Observer	8. Kalman filter	9. Model predictive comtrol	10. Adaptive control	11. H_∞ optimum control	12. Optimization control	13. Rule based control	14. Fuzzy control	15. Neural network control
1. Safety & stability	■	■	■	■	■	▨	▨		■	■			▩	▩	
2. Productivity												▩			
3. Yield improvement															
4. Quality improvement	▩	▩	▩	▩	▨	■	■	■	▩	▩	■				
5. Energy saving												■			
6. Man power saving	▨	▨	▨	▨	▩			▩					■	■	▩
7. Operability															■
8. ,High-technology						▩	▩								
99. Others															

■ Top mark
▩ Second top mark
▨ Third top mark

[By courtesy of the JEMIMA]

Evaluation of Results

Evaluations of application results are shown in Fig. 7

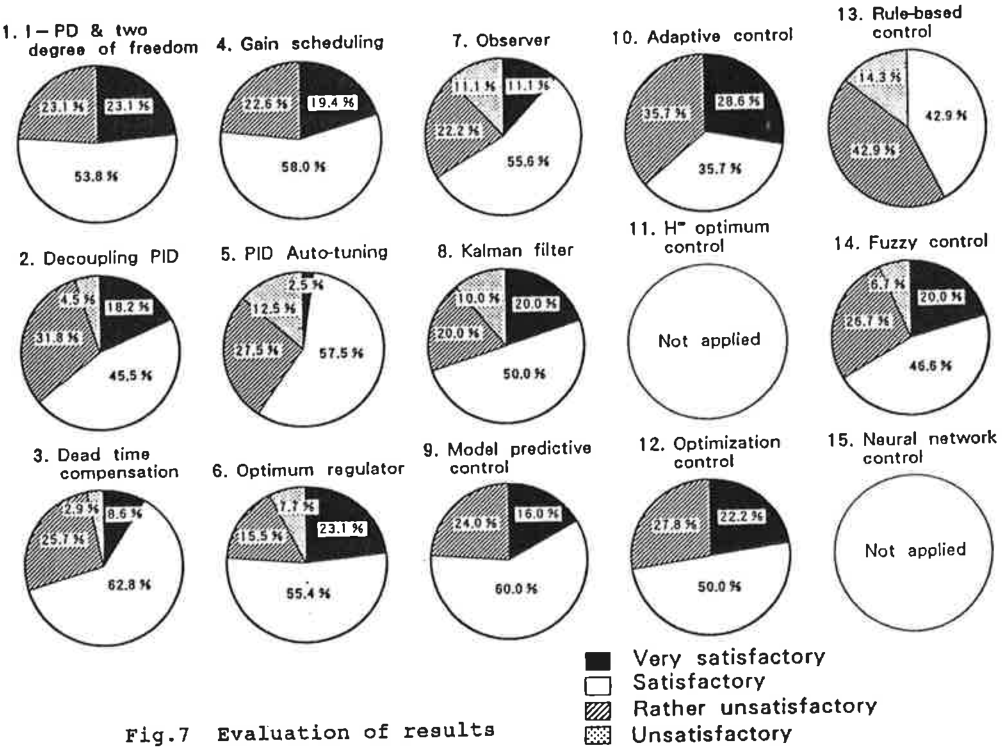


Fig.7 Evaluation of results

[By courtesy of the JEMIMA]

- Advanced-PID-type control is widely applied. Sixty to 70% of respondents are satisfied by the results, but satisfaction is rather low for decoupling control and auto-tuning control.
- Although modern control theory is not applied much except for model-predictive control, 60 to 70% of respondents are satisfied with this control type. The percentage is equal to that regarding PID control. There has been no actual application of H^{∞} control.
- In the category of AI, there has been no actual application of neural networks. The application of rule-based control is small compared with that of fuzzy control. Though there are favorable responses, this method should be evaluated through many future applications.

HIGH-LEVEL CONTROL TECHNOLOGY APPLICATION

At present, most plants are controlled by PID control for each unit of loops, such as flow control loops, pressure control loops, and temperature control loops. This configuration satisfied the control purpose in many cases. The PID control method has many advantages from a practical point of view. However, actual plants have the following difficulties, so that it may be problematic to restore them to a stable condition once the system balance is disrupted for some reason.

- Non-linearity
- Complicated interaction among variables
- Intricate dynamics that change depending on operating conditions
- Disturbances which upset system stability

One reason that the current control method is satisfactory in spite of the above difficulties is the existence of an operator. The system is stabilized by automatic control during steady states. During unsteady states, however, the operator occasionally adjusts the PID parameters or operates the plant manually in order to restore the system to a stable condition.

First, if the level of plant automation is to be increased, the parts currently dependent on manual operation should be automated. For that purpose, a *high degree of robustness* and *adaptability to environmental change* are required for control loops. For instance, there are cases in which the controller gain is changed manually by the operator, by observing the response curves and the degree of oscillation of process variables. This is because the controller has insufficient robustness. Accordingly, it is necessary either to install sufficient robustness in the controller, eliminating the need for gain change, or to deploy an automatic gain change mechanism within the controller.

Second, it is important to recognize the plant as a multiple input and output system. It is necessary, at least, to consider the plant as a group of unit operations, not as a sum of independent control loops. The concept of control should also be changed from that of loop control to unit control. Nevertheless, static and dynamic relations among variables are still too complicated. Even if PID control is employed with the use of decouplers, these problems cannot be resolved. In addition, because it is nearly impossible to express these relations by a linear, time-invariant mathematical model, modern multi-variable control theory, although it can be applied here, cannot solve these problems completely.

Third, *control safety* is required so that the entire plant will not enter a dangerous condition even if instability arises in a certain variable for some reason. In today's systems, although interlocks are used by the combination of high and low selectors and logic circuits, the operator's intervention is presupposed as a last resort.

It is important to solve these three problems:
•Automation of parts dependent on manual operation
•Recognition of plant interaction complexities
•Control safety

Given these existing problems, there are various approaches that can be considered to automate the plant:

Expert Control System

If it is necessary to automate a plant while its nonlinearity and the interaction among variables are not fully understood, one solution is that all the operations currently performed by the operator are converted into rules, which are then executed by the computer. The scope of the automation depends on how proficiently the operations are converted into rules. But because it only emulates operations performed by the operator, the computer cannot be expected to improve performance above the level achieved by an operator. Nevertheless, it is a positive step toward an increased level of automation.

Another possibility is to use fuzzy control, which still has some limitations. But in order to repeat exactly the operations performed by the operator, additional functions are needed beyond the present capabilities of conventional fuzzy control.

Construction of Mathematical Models

As mentioned above, plant behavior is complicated and cannot be expressed simply by a linear dynamic model. A multivariable model becomes necessary, but its development is extremely time-consuming. However, it is not necessary to create a model that behaves in the same way as an actual plant in all its aspects. In designing a stable control system, it is sufficient that the plant behavior be expressed adequately, given its required purpose. Depending on the purpose, e.g., control system design, fault-diagnosis system design, or training simulator development, the degree of precision needed in the mathematical model will vary accordingly. In any case, the model will become considerably complicated. Fortunately, given the current progress trends in computer technology, it is expected that computation capability will be further increased. Even now, a fairly complex model can be employed in practical use to some extent. Process analysis and identification systems fully using computer capabilities can facilitate the tedious task of constructing process models. So far, procedures for developing these models are still at a primitive stage; it is desirable to create better procedures that can accommodate nonlinear, time-variable system identification.

If construction of such a process model is successful, then a high-level control system can be developed based on the model. When compared with the conventional expert control system, the new system would attain a higher level of competency than the older system, by "growing" with the input of acquired plant knowledge.

OPERATION IMPROVEMENT

Due to personnel reductions, the area of a plant to be monitored by any given operator will expand. Thus, computer-aided abnormality analysis and operation support systems become important. In Japan as well as in other nations, many operation support systems are being developed.

One type of operation support system is the process diagnosis system. A future goal is that this system be available for use at all times—not only during abnormal states, but also for daily operations, such as operation at normal states, startup and shutdown, recipe change, and batch operation. A general form of the abnormality-diagnosis system is considered. The scheme, from reading sensor signals to taking action, may be noted in Fig.8. At each step of process knowledge or diagnosis, both the expert control method and the mathematical model may be used. The learning step indicated in the figure has not been realized yet but, in the future, this step will be implemented in the system.

Another type of operation support system stresses quality assurance management. In Japanese chemical companies, quality assurance is still one of the most important topics. To solve this problem, Japanese chemical companies for some time have been actively using the Statistical Quality Control (SQC) approach. The current enthusiasm for the "new" Statistical Process Control (SPC) approach has puzzled Japanese industry and academia, as it seems essentially identical to the SQC that has been applied in Japan for decades. Some differentiation between SPC and SQC is desired, and it is hoped that SPC will provide an innovative, enriched approach

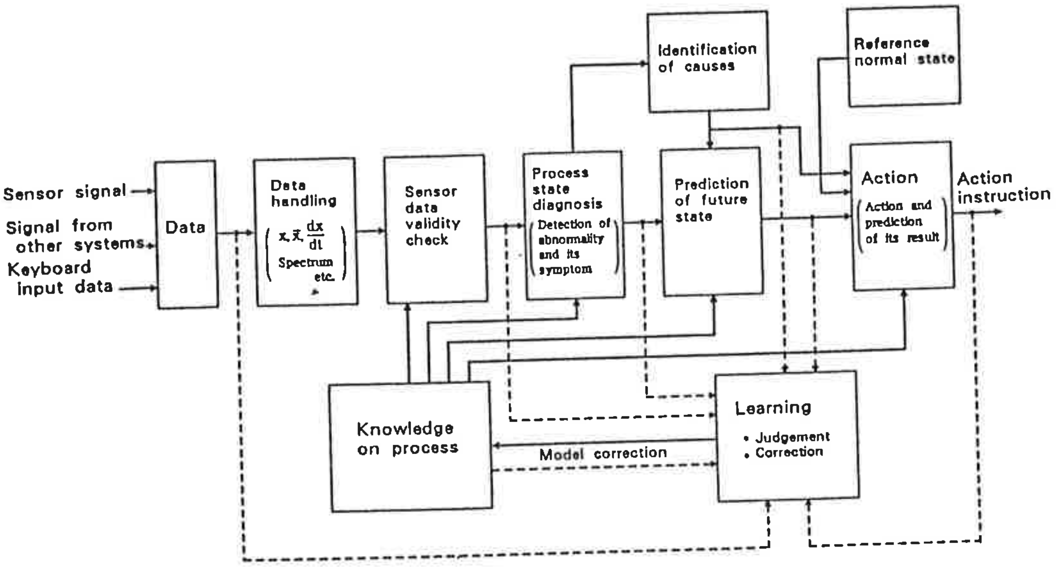


Fig.8 Schematic structure of a future process diagnosis system

toward enhancing quality assurance. One prospect for SPC research involves creation of an intelligent operation system in which the statistical approach and the process control approach are harmoniously united for improving process productivity and product quality.

A trait that all operation support systems should share is a capability for easy upgrading.

FLEXIBLE PRODUCTION SYSTEM

In order to enable multiproduct, small-quantity production, the control and management system should have the flexibility to cope with not only recipe changes but also alterations in the configuration of production facilities. Figure 9 shows an example of the hierarchical system for the production system of a batch process. The levels have the following functions:

•Scheduling

Automatic allotment of proper facilities for each production and generation of the optimal schedule for each production line.

•Handling of recipes

Management of each product.

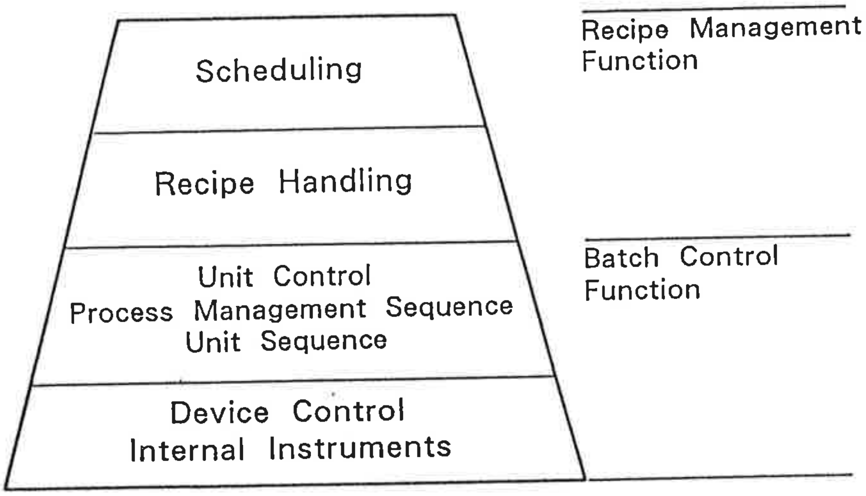


Fig.9 Hierarchical structure of recipe management and batch control function

- Unit control

  Control of each facility.
  - Control of mode or status, such as automatic/semiautomatic/manual mode, stop/run/hold status, etc.
  - Control of the order of processings, such as charging, heating and maintaining reaction. (Management of processing sequence)
  - Control of the sequence of basic actions within each processing. (Management of the sequence of basic actions in each processing)
- Device control

  Control of equipment and instruments such as valves, motors, etc.

Here a more detailed explanation of unit control is added. In the standard control and management system, a valve, a temperature control loop, or a batch counter is usually considered as a unit. In batch processes, however, it is more useful to regard a production facility, such as a reactor, as a macro-control unit. By considering it in this way, the design problem of a control system for a batch process can be understood much more easily and also it becomes easier to provide a control system with ample flexibility. Hereafter this macro-control unit is termed a "unit."

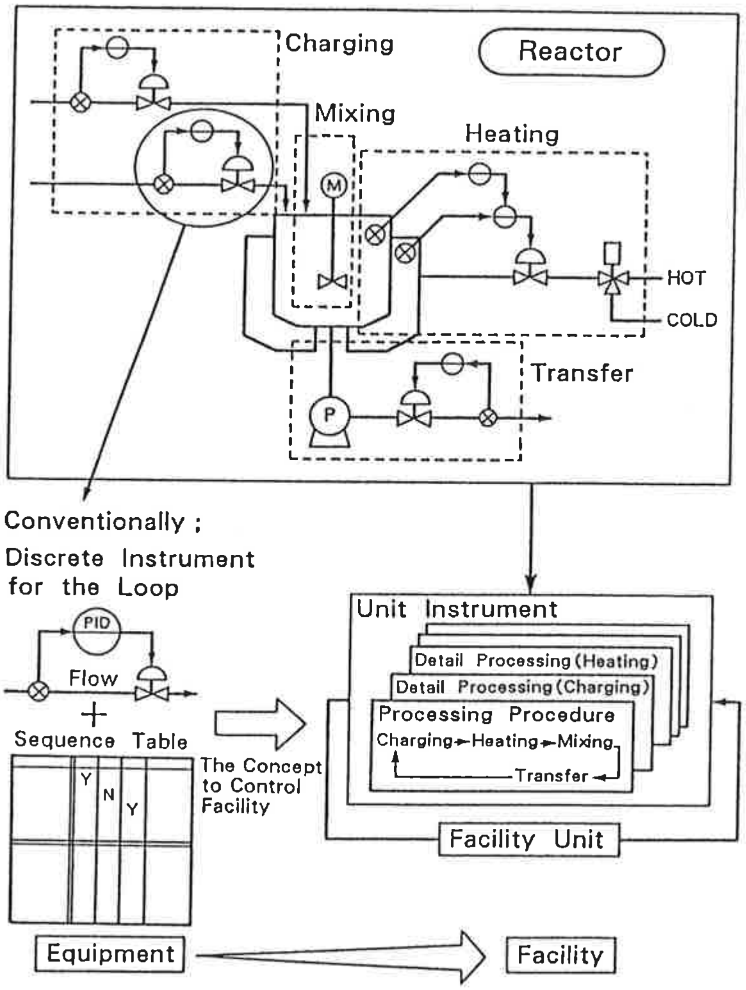
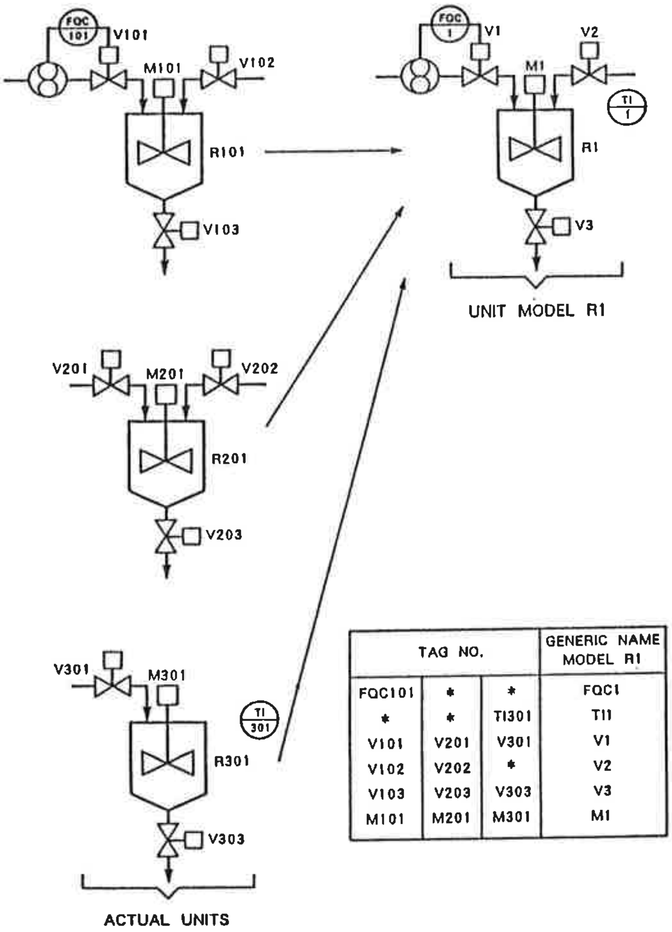


Fig.10 Concept of unit instrument

In Fig. 10, a reaction facility consists of a charging unit, a mixing unit, a heating unit, and a transfer unit.

Concerning the unit, the concept of "unit instrument" is introduced. This unit instrument can receive plural inputs from a corresponding unit, and provide plural outputs to the unit. The setpoint value of a unit instrument is a production recipe given by the recipe management system, located on a higher tier in the figure. The production recipe includes information specifying a sequence of necessary



TAG NO.			GENERIC NAME MODEL R1
FQC101	*	*	FQC1
*	*	TI301	TI1
V101	V201	V301	V1
V102	V202	*	V2
V103	V203	V303	V3
M101	M201	M301	M1

Fig.11 An Example of unified unit model

processes, a desirable temperature pattern, and so on. According to the production recipe, the unit instrument controls the corresponding unit in order to produce the product just as the recipe specifies. The "unit" concept is introduced to make design procedures of the control and management system more efficient and also to increase flexibility of the designed system. That is, when defining a certain unit, we prepare a unified model beforehand in which variations can be included. Figure 10 shows an example of reaction process. By using the unified model of a unit as shown in Fig. 11, instrumentation design can be performed even before the necessary information on actual production facilities becomes available.

AUTOMATION OF MAINTENANCE, SECURITY, AND ANTIDISASTER FUNCTIONS

One obstacle, when promoting personnel curtailment, is that the number of field personnel is difficult to reduce. Because tasks of field personnel include facility maintenance, inspection patrol, or temporary work during emergencies, such as fires, it is difficult to automate these tasks with current technology. Nevertheless, detection of gas and liquid leaks is essential. Sogo Keibi Hosho Inc., a security company, and the Tokyo Fire Defense Board are now planning to develop a robot with visual and auditory functions to fight building fires. Sugino Machines, a medium-sized industrial machinery manufacturer, and the Power Reactor and Nuclear Fuel Development Corporation (PNC) have jointly developed a robot that walks on pipes by remote control, and checks for cracks in the piping. Expectations for these projects are high. Yet because these robots require not only manipulation mechanisms, but also high technology, such as pattern recognition of voices and images, there are quite a few problems to be dealt with in the future.

FUTURE RESEARCH NEEDS IN THE JAPANESE ACADEMIC FIELD

This section addresses future trends and needs in research taking place in Japan. Toward that end, first current research is described, with a practical example given from an impact copolymer production system. Figure 12 provides information on current research related to chemical process control being done at Japanese universities.

The Kyoto University group is now covering topics related to data analysis, control, scheduling, and process design. Fortunately, this has exceptionally good collaboration with the corporate sector and has relied on such collaboration in addressing process control problems. The example below is intended to help identify concrete problems that need to be resolved in the future.

Impact copolymer production system

In order to produce impact copolymers, one or more secondary reactors is necessary, as shown in Fig.13. A homopolymer and an ethylene-propylene mixture react in the secondary reactor, producing an ethylene-propylene rubber (EPR) in addition to homopolymer powder. To produce specific grades of product, each satisfying strict quality requirements, e.g., stiffness, elasticity, and gloss, a resin's properties are tailored. These properties include comonomer concentration, rubber concentration, molecular-weight distribution, viscosity, and density.

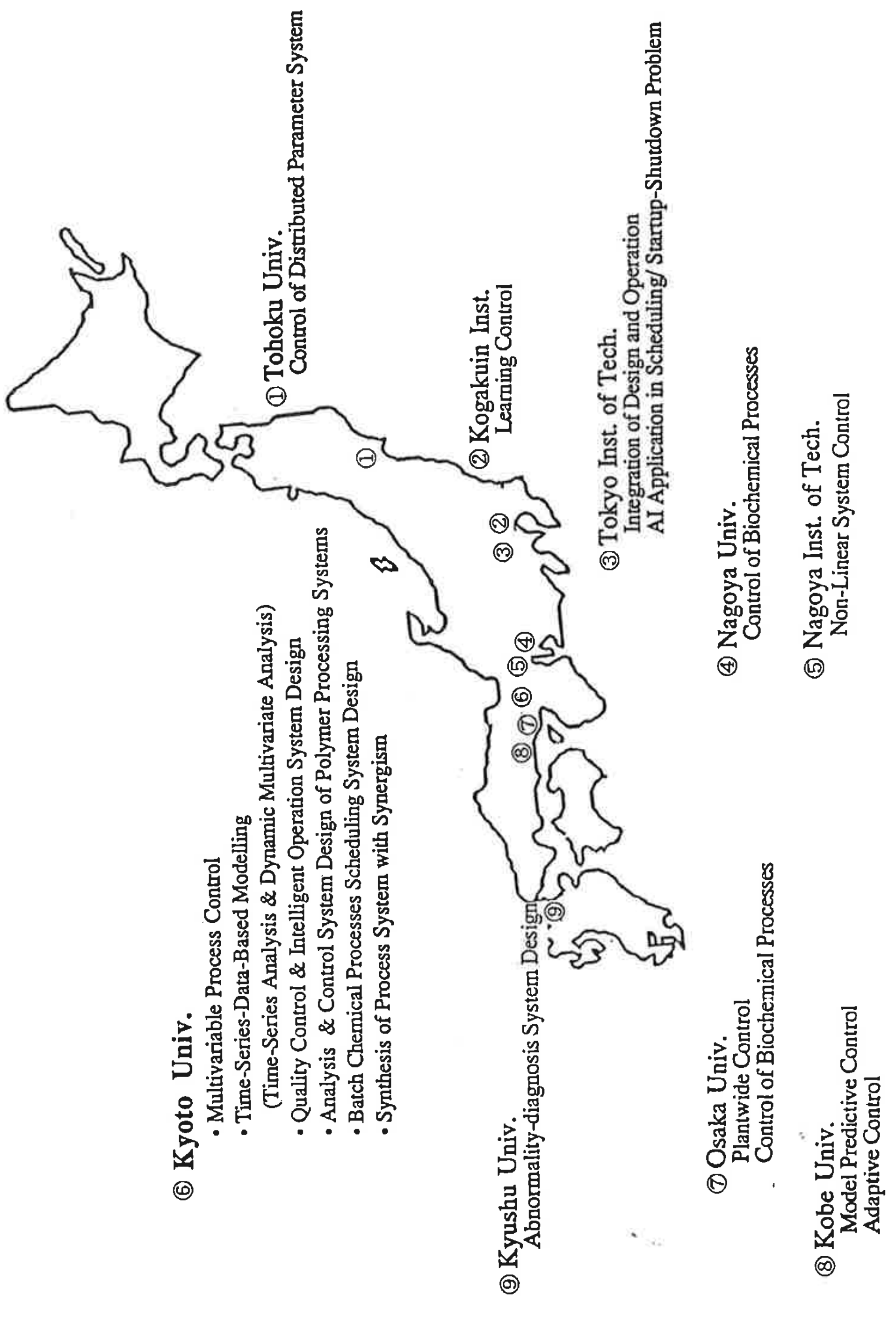


Fig. 12 Japanese academic reseach on process control

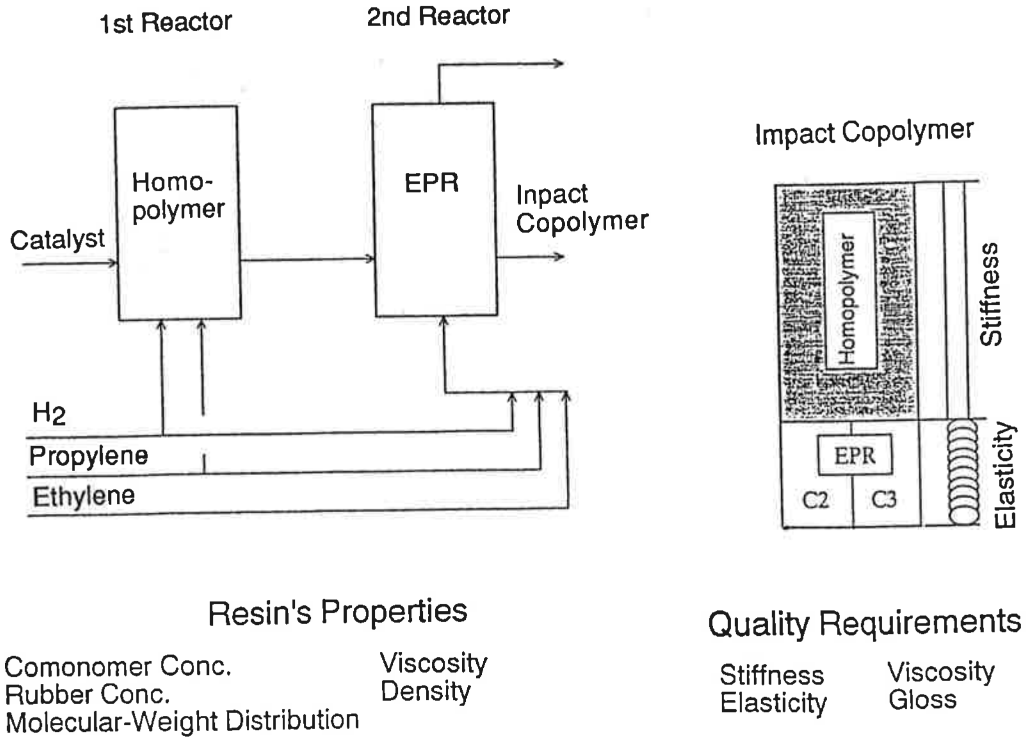


Fig. 13 Schematic diagram of impact copolymer prodction system

For a long time, researchers have been discussing modeling problems on the process side, that is, the problems of how to build models between inputs and out variables. Reliable process models play crucial roles in designing sophisticated and advanced control systems and in developing more capable operation systems as already discussed in previous section.

The importance of modelling on the quality side should be emphasized. The task is to integrate quality problems and process control problems; in order to do so, a model is required that can translate information on product quality requirements into specifications for physical state variables in the process (Fig. 14.) In building such a model, (quality modelling) it is necessary to combine profound theoretical knowledge, empirical knowledge, and various types of know-how accumulated in the past. The methods available for constructing a model that includes quality requirements are few in number and not sufficiently effective. Only multivariate

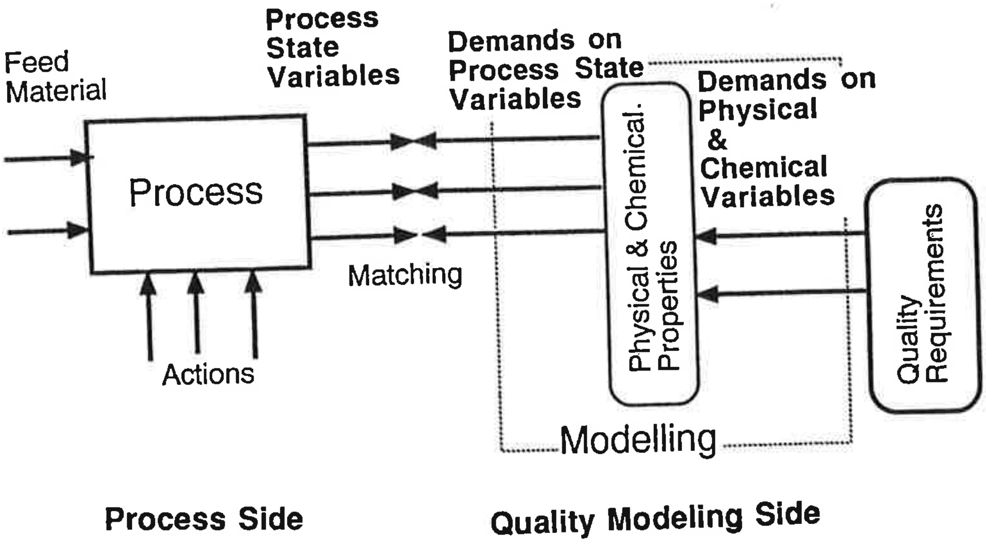


Fig. 14 Impact copolymer production

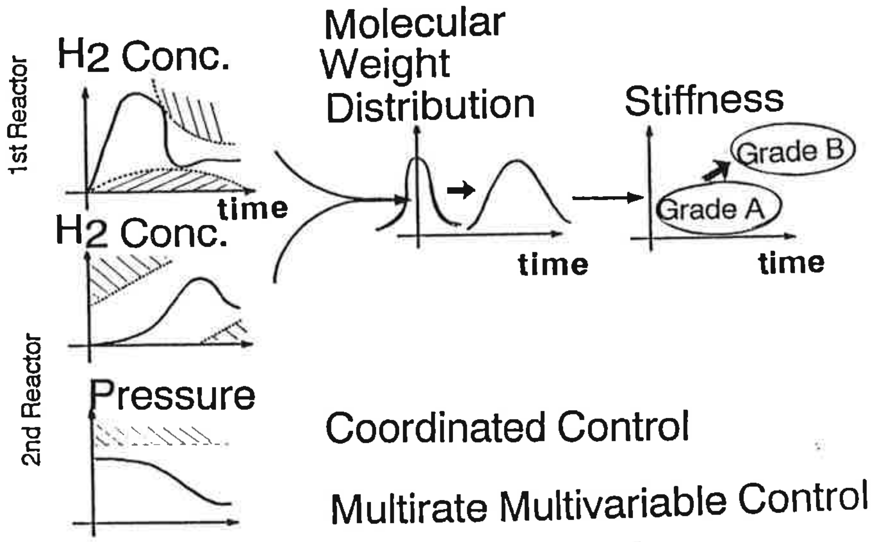


Fig. 15 Optimal transient path for grade change

analysis is commonly used, but it is still unsatisfactory. In the future, a more effective systematic procedure will be essential.

On the process side, the process must be operated and controlled so that process state variables can meet the demands derived from this model. As may be expected, some problems have emerged.

In impact copolymer production, a large number of different product grades are produced. The operation condition must be changed from one grade to another safely and as quickly as possible. First, the optimal transient path is identified in a very narrow feasible operation region that is determined by many constraints. Figure 15 shows selected process state variables, each with an optimal path and constraints which must be obeyed. If process state variables can be made to follow their optimal paths, then the product's physical and chemical properties, for example, molecular weight distribution, can in turn be changed. Finally, necessary changes in quality requirements can be performed quickly and safely. In order to ensure that state variables of the reactors follow the optimal paths, both reactors should be controlled in a well-coordinated manner. Thus the control problems of the whole system are managed not as a mere sum of independent control loops but as a group of control loops that must maintain a synergistic relationship.

Process state variables include pressure, temperature, flow rate, liquid level, and concentration. Some of these variables, such as temperature and pressure, are measured very quickly and without much difficulty, but measurement of other variables can be time-consuming. For example, when concentration is measured using gas chromatography, the time required is long compared with temperature measurement by thermocouplers. Such differences in required times for these measuring techniques influence how this type of process control design problem is viewed. Control problems of systems in which each control loop has a different sampling period must be considered in terms of multi-rate, multi-variable control.

The lack of proper on-line sensors for directly measuring variables has been a problem for some time; sensors are especially needed in directly measuring product quality. Often there is no suitable testing and measuring system available to ensure that product quality meet customer requirements. Even when such a device is available, it is often the case that only destructive or off-line measurements are possible and that the product's properties can be measured and analyzed only through lengthy, time-consuming processes. Development of non-destructive and on-line measuring devices or sensors is indispensable. However, it usually requires

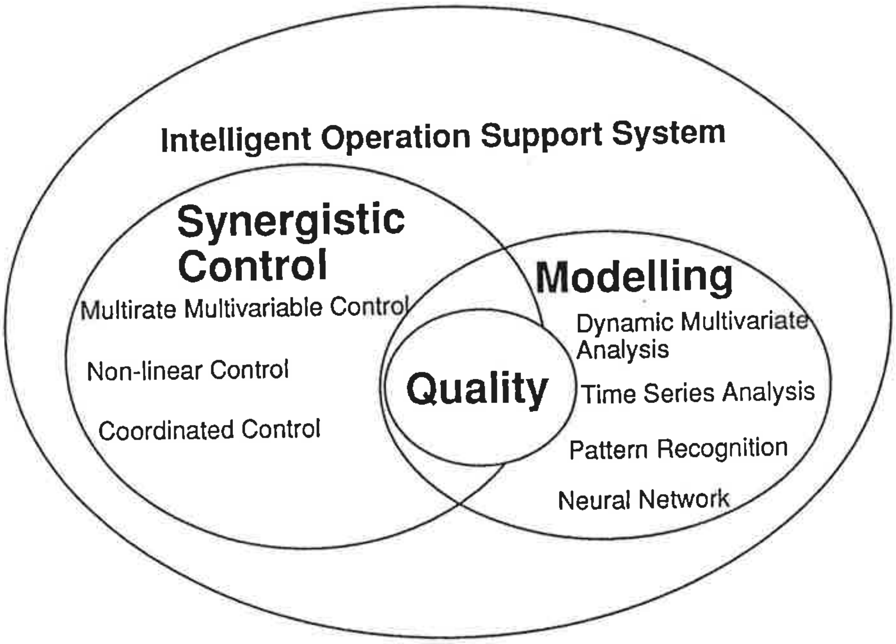


Fig. 16 Future reseach for intelligent operation system

considerable time to invent and develop such devices or sensors for actual industrial use. One possible solution might be found in the development of computer-aided estimation systems, which enable measurement of those qualities that cannot be measured directly, by processing data on many other measurable variables.

Here, some issues that future process control research in process control must address are presented. Traditional process control has focused on the quantitative side of production. Yet recently qualitative concerns are being viewed as crucial in control engineering.

Two points should be clarified as shown in Fig. 16. First, in modelling, quality requirements, as well as process requirements, ought to be emphasized. The second point involves perspectives on control. A system's synergistic effects—the benefits resulting from positive interaction of various variables in a nonlinear arrangement—should be acknowledged and valued at the design stage as a desirable feature of control systems. Additionally, because the time required for measuring system variables varies widely, the system must be considered as a multi-rate, multi-variable system. This consideration, and an increased emphasis on synergistic effects, should be taken into account when creating a theory of control system design.

In both modelling and control system design, better data analysis is needed. One possible path for realizing this goal requires that data analysis techniques developed by statisticians be united with process control techniques and methodologies developed by control engineers. For this purpose, it is necessary to refine advanced analysis methods for handling time-series data and to improve methods for pattern recognition. Further, improvement of methods for handling other types of dynamic multivariate data is a pressing concern.

CONCLUSION

Effects on the Japanese economy caused by changes in demographics and lifestyles have prompted creation of a strategy for coping with these changes. It entails production information integration, hyperautomation, cost reduction, and human resource recruitment. An additional concern involves required technology for executing this strategy.

Statistics from a survey on the state of the art in Japanese process control indicate that PID control still predominates and is sufficient for most needs. Control engineers claimed enthusiasm for newly developed advanced control techniques that are appropriate for more difficult control problems. A renewed emphasis on quality improvement and the expanding role of control engineers were cited as contributing factors.

Preparation needed to adopt new advanced control techniques includes the development of mathematical models. This development must occur despite inherent difficulties posed by the characteristics of chemical plants, such as non-linearity, complicated interaction, and changes in dynamics over time.

Unifying process control techniques and statistical approaches is a key goal for enhancing quality assurance.

With the diversification of customer demands, flexibility in production systems will aid in reducing inventory, and realizing Just-In-Time production.

Future research needs in the Japanese academic field were examined through the example of an impact copolymer production system. New emphases on synergistic control and quality modelling are advocated. Further research should be directed toward development of an intelligent operation support system, which would ease present concerns including quality assurance, safety, fault detection, and personnel reduction.

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