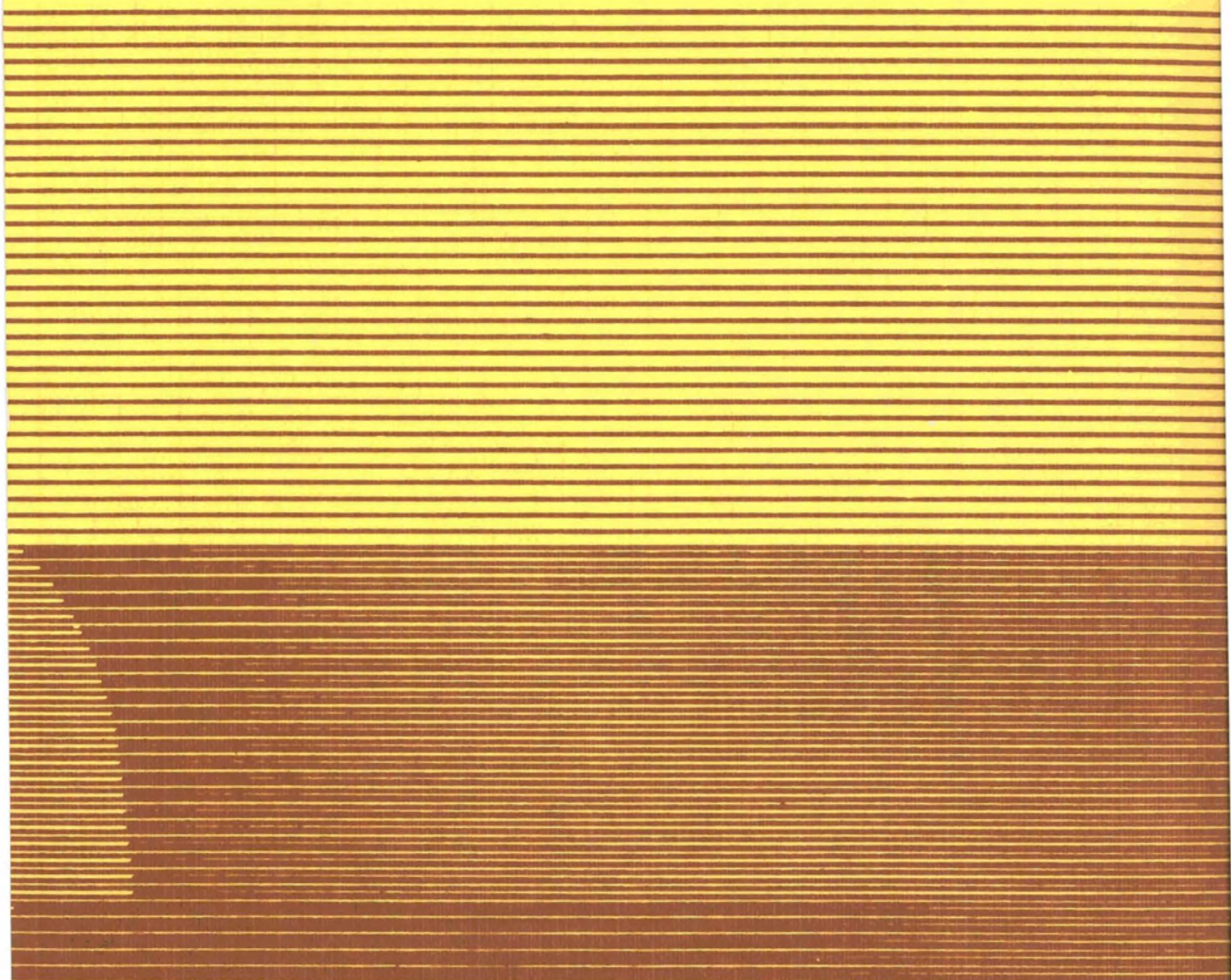


INTEGRATED SYSTEMS CONTROL IN THE STEEL INDUSTRY

STATE-OF-THE-ART REVIEW AND
PROCEEDINGS OF THE CONFERENCE
JUNE 30 - JULY 2, 1975

I. LEFKOWITZ and A. CHELIUSTKIN, Editors

DECEMBER, 1976
CP - 76 - 13

CP-76-13

INTEGRATED SYSTEMS CONTROL IN THE STEEL INDUSTRY

STATE-OF-THE-ART REVIEW AND PROCEEDINGS OF THE CONFERENCE
JUNE 30-JULY 2, 1975

I. LEFKOWITZ and A. CHELIUSTKIN, Editors

DECEMBER, 1976

International Institute for Applied Systems Analysis
2361 Laxenburg, Austria

Preface

This volume comprises a State-of-the-Art Review of Integrated Systems Control in the Steel Industry, and the proceedings of the Conference on Integrated Systems Control in the Steel Industry.

The Review was first distributed in draft form on 6 June 1975 to those who participated in the state-of-the-art survey and in the Conference on Integrated Systems Control. Its purpose was to provide background material for the Conference and to motivate constructive feedbacks that might be helpful in the preparation of the final report. The present version of the review has been revised and expanded, reflecting various inputs derived from Conference discussions and subsequent written comments. We gratefully acknowledge these inputs which we feel have contributed to the usefulness of the final report.

The State-of-the-Art Review summarizes efforts of the Integrated Industrial Systems Project of IIASA over the period July 1974 to May 1975. The initial phase of the study involved visits by members of the project to various steel companies and research institutes around the world in a survey of the "leading edge" of the state of the art of integrated systems control. A questionnaire sent out to steel companies visited in the survey is included as Appendix 2. The list of companies and institutes visited in conducting the survey is included as Appendix 1. We acknowledge with thanks the assistance given us by all those who cooperated in this effort.

I. Lefkowitz, D.H. Kelley, and A. Cheliustkin were responsible for the contents of the State-of-the-Art Review. The overall organization and technical editing was done by A. Cheliustkin and I. Lefkowitz.

The report preparation was a group effort to which all members of the Integrated Industrial Systems Project contributed. In particular, we acknowledge the assistance of B. Mazel and G. Surguchev of the project team. Finally, we are indebted to Mr. Terry Seal for his editing of the Conference Proceedings and his labors in achieving a more readable result.

The Conference on Integrated Systems Control in the Steel Industry was held at Laxenburg June 30 - July 2, 1975. It was attended by representatives of steel industries and research institutes from many countries. They contributed to the Conference in formal presentations and in discussion sessions which are included in this volume.

If we are to identify one person to be credited with the accomplishments of the survey and to be recognized for his contributions to this report, he is without question the late Professor Alexander Cheliustkin of the Institute of Control Sciences, Moscow, who shared with me the leadership of the Integrated Industrial Systems Project. It is with deep-felt sadness that I report his death on February 27, 1976. He was working on the final editing of this report until almost the end, and it is unfortunate that he could not see the fruits of his labor in published form.

Professor Cheliustkin brought to the project many years of experience in the area of systems control, with specific expertise in applications to the steel industry. He was enthusiastically committed to the goals of the research program and he devoted very considerable energy and effort to their fulfillment. We enjoyed a good working relationship as project co-leaders and a warm personal relationship nourished by mutual respect for our commonalities as well as our differences. Indeed, he exemplified that spirit of international scientific cooperation —— particularly East-West ——that underscores the purpose and the hope of IIASA.

It is to the fond memory of Alex Cheliustkin that we dedicate this report.

I. Lefkowitz
August, 1976

Abstract

Integrated systems control has as its goal the integration of the information processing, decision-making and control functions of an industrial system to achieve increased operating efficiency and productivity, better utilization of resources, improved product quality and other benefits. As the steel industry is well advanced, relative to other industries, in the application of highly computerized systems integration, it was selected as the basis for a first case study.

The Review presents both the results of a state-of-the-art survey of integrated systems control in the steel industry and the proceedings of a IIASA conference on the subject. The results motivate a general methodology for integrated control system design based on a hierarchical structuring of the system, incorporating multilevel decomposition and temporal and functional multilayer concepts.

Table of Contents

Opening Remarks

Lefkowitz

I have asked Dr. Roger Levien, the Director-Designate of the International Institute for Applied Systems Analysis (IIASA), to say a few words of welcome and also to present a little of the background of the Institute and of the Conference.

Levien

Thank you Professor Lefkowitz. Let me extend greetings to you from Professor Raiffa, the Institute Director, who is preparing to leave on a trip to Rumania this afternoon and therefore could not come. He shares with me the delight that all of you could join us for this three-day Conference on the Integrated Industrial Systems Project. I see a number of familiar faces in the audience, people I have talked to and who I know have visited IIASA before. I am not sure that each of you knows about our organization and I would like to take just a few minutes to give you a little bit of the background as a context in which you can carry out your own deliberations.

Let me say something about the past of IIASA, its present, and just a few words about its future. As you may know, the Institute arose from a suggestion at the end of 1966 that there should be a research institute somewhere in the world concerned with the common problems of the developed countries. The suggestion came out of the American White House under Lyndon Johnson, and it was taken up quickly by the Soviet Union. During the period from 1966 through 1972 there was a series of negotiations in ever-widening spirals engaging more and more countries about the creation of an institute which, at one time, was called the Institute for Common Problems of Developed Countries and then, for a while, called the East-West Institute. Finally, in October 1972 the Institute was created in a charter signing ceremony in London as the International Institute for Applied Systems Analysis. Soon thereafter, there was an offer from the Austrian government to locate this new Institute in these very elegant quarters we are now in and in May 1973 the first scientists moved into the then partially finished Schloss Laxenburg.

In slightly over two years, the Institute has built up at a rather rapid pace and we have now reached the stage of having about 70 scientists working on 11 research projects, having 14 national member organizations, and an annual budget of about $5 million.

Let me say something quickly about our current status. I mentioned 11 research projects. They fall into three basic categories. First there are six projects that we called our applied projects. I should list first among that group the Integrated Industrial Systems Project, the project with which you will be concerned for the next three days. You will learn much more about it in the course of this time so I will not go into it in detail. The second applied project is the Energy Project led by Wolf Häfele from the Federal Republic of Germany; this Project is concerned with exploring alternative energy futures for the world, and it is looking at alternative technologies and the ways in which they imbed themselves in the environment and the economy, and how these technologies may occur in the general social problems of the future.

We have a project, Ecology and Environment, concerned with the management of ecological systems. It has worked on the ecological systems of forest pest management, for example, management problems of the spruce budworm, a stubborn pest endemic to Canada, the United States, Poland, Japan, and so on. The project has worked on Alpine ecologies, fragile ecologies now being submerged under human and industrial demands, and they are looking at an international ecology, the fisheries of the Northwest Pacific, in particular the salmon fisheries and how they might be managed. This project is under the leadership of C.H. Holling of the University of British Colombia and Carl Walters, his deputy, who is with us at IIASA this year.

We have a Water Project headed by Z. Kaczmarek of Poland that is looking at river basin management in such basins as the Tisza River basin in the CSSR, Hungary, Yugoslavia, Rumania, and the Soviet Union and the Vistula River basin in Poland.

We have an Urban and Regional System Project, led by Harry Swain from Canada, that has been looking at national settlement systems. These systems are concerned with the problem of population distribution, the distribution of productive forces and the distribution of urban settlements in nations. We have been doing both a comparative study of such policies in a variety of countries and an examination of the scientific methodologies for studying such problems. The project has also been studying municipal system management and it is now working on resource conserving urbanism, that is, the ways in which we can develop cities at a minimum cost in resources and energy. Now, I have mentioned Integrated Industrial Systems, the Energy, Ecology, Water, and Urban Projects. A sixth project is Bio-Medical. This project has had a number of different concerns, but at the moment they are interested mostly in two topics. The first is the modeling of national health care systems and developing better information about the structures of such systems, in particular comparing the various organizational forms and the allocating of resources for health care systems around the world. The second topic concerns developing information systems for the management of research in bio-medical areas on an international scale, for example, an information system that would give us data about cancer research internationally so that such research could be coordinated and proceed in a cooperative way.

These are our six applied research projects which you might imagine as the colums in a matrix. Cutting across them in another dimension are our three supporting research projects. One is our Methodology Project, that was led at first by George Dantzig, one of the inventors of linear programming. He was succeeded by Tjalling Koopmans, an economist, and then by William Jewell of the University of California at Berkeley who is in operations research. Starting this September, the project will be led by Michel Balinski who is well-known in mathematical programming and applied mathematics. The Methodology Project has a number of different purposes. But there are really two that dominate. First, the project provides expertise for the broad range of methodologies that contribute to systems analysis. As we expected, we have been quite pleased to see that the methodologists have been working as a part of the teams addressing the applied problems throughout the six projects that I have mentioned. Second, the project, hopes to contribute to the advancement of the systems analysis methodology. Starting with George Dantzig and our other contributors, we have indeed been able to add to the state of the art.

The second supporting project is our Computer Science Project which is led by Alexandre Butrimenko from the Soviet Union. Here we are concerned most immediately and most explicitly with the development of computer networks, both in theoretical terms, trying to understand the methodologies of computer network design, and in practical terms--for IIASA is, in a sense, a prototype of the kind of research organization that needs to be linked into a computer network. For several reasons, such as our small size, we can afford only a relatively small computer system. We need to have access to more powerful systems and, indeed, we have developed a primitive network that enables us to communicate over telephone lines with computers in Frankfurt and Vienna, and occasionally in Bratislava, Budapest, and Moscow.

As an international organization with a continually changing staff, we need to provide scientists here with access to their home computers or to computers comparable to those they have used before so that we do not have to translate every program into a new language in a new facility. Thus, we have a practical interest in computer networking and we are building to create or to become the node of the network extending both into the eastern countries and the western countries so that over the next few years we expect to have lines linking IIASA with Moscow, Budapest, Warsaw, Bratislava, as well as Frankfurt, Bern, Munich, Paris, and so on, on a long term basis. Clearly, the major focus of our Computer Science Project is computer networking. But I should mention as well that the project has supported the IIS Project in such activities as computer-aided design, including a world survey of computer-aided design carried out during the early part of last year. I will say a word more about that below.

The third supporting project is the Large Organizations Project and it is headed by Hans Knop from the German Democratic

Republic. This project has developed a focal interest in the management of regional development and it has expressed this interest in two major retrospective surveys. The first, which was stimulated by a conference held here last November, is a retrospective survey of the Tennessee Valley Authority of the United States. That, as you know, is a major regional development, now 40 years old, in the southeastern parts of the United States. That survey is now being followed up by on-the-spot visits, and in December 1975 we hope to make a comparable survey of the Bratsk-Ilimsk dam development in Siberia in the Soviet Union. The Large Organizations Project is very much interested in learning from the experience of prior regional development activities, both in the United States and in the Soviet Union.

There are two other projects that I have to mention. One is what we call our General Activities Project. Like all organizations, we need a category that one might call miscellaneous, a place in which new ideas can be tried out, tested, and evolved. General Activities at the moment is concerned with two subjects: first, global modeling, and many of you know about the work Forrester, Meadows, Mesarovic and Pestel, and the Fundación Bariloche have done in developing global models. IIASA is not yet engaged in this work itself, but we feel a special responsibility to follow it since our interests are fundamentally global and we want to observe, to study, and to disseminate information about global modeling. A major activity of our General Activities Project is just that. We have already had two conferences, and shortly we will have a third conference on the various global models.

The second activity of the General Activities Project is food and agriculture. We are beginning to get into this issue which is obviously of global concern. Within the General Activities Project the seeds are being planted from which a subsequent large project on food and agriculture may grow.

I have left for last the project that I, over the past year, have been the most concerned with personally; this is what we call our Survey Project. One of IIASA's fundamental roles is as a node and an information dissemination and gathering network. We have brought together people from around the world to work here; and we are trying also to assemble information, information about the state-of-the-art of systems analysis as it is practiced internationally. However, we do not want only to assemble information; we want to disseminate it and further we want to serve as a place that can help in exchanging this information between countries. The Survey Project has that as its goal, and it approaches it through two different kinds of publications. First, we hope to produce, in the next two years, a handbook of applied systems analysis. We are thinking in terms of a single volume of perhaps 1,000 pages, with 50 or 70 chapters that will distill the relatively unchanging aspects of systems analysis, put them in a form that can be easily used as a basic reference around the world. But that is a rather concise format for conveying a rather new, broad, and rapidly changing field of discipline. So in parallel with that handbook, we are arranging to publish a series of state-of-the-art volumes, each one of which will take a specific aspect of systems analysis and undertake a 200 to 400 page survey of it in a form that will be useful to practitioners of systems analysis. We expect to publish eight to twelve such volumes each year on a continuing basis. For both the handbook and the series, we have made arrangements with John Wiley and Sons, a fairly well-known international publisher, to publish the English edition; we are arranging also for translations.

I have mentioned above that I would have a further comment on computer-aided design. One of the first volumes in our series on the state-of-the-art of systems analysis will be a volume on computer-aided design, to be edited by Josef Hatvany and Malcom Sabin from Hungary and Great Britain, respectively, and with many contributors from around the world.

That is the current state of IIASA: 11 projects, many separate tasks, 70 scientists, an annual budget of about 100 million Austrian schillings or roughly, US $5 million, and a scientific research program about two years old. Now let me say something very broadly and very quickly about the future.

We feel that IIASA is now coming of age. In the future, we have to extend and build on the strengths that we have started to develop; we have to produce a more comprehensive and coherent research program with sharper focus. We probably will be devoting our attention to a number of major issues, trying to concentrate the work that has been done thus far on questions of major world-wide concern. One such question certainly will be in the area of energy, looking more broadly and deeply at energy prospects through the year 2000. A second likely area of focus is the area of integrated regional development, the ways in which industrial development, town planning, population distribution, health care, education, environment, and so on can be taken into account in the planning of new regions and their evolution. We will retain and hope to strengthen our integrated management, not only on the regional level, but also on the national level. We have a fundamental concern with industry as one of the key processes in modern industrial society. That is a short, quick survey of the past, present, and future of IIASA.

Let me just return to the Integrated Industrial Systems Project a second. We welcome you here to consider this project and we point out that in many ways it is a prototype IIASA project. It has a scientific staff, as you can see, drawn from many of the countries, both socialist and non-socialist, that belong to IIASA. It has had an opportunity over the last year to explore the state of the art of a particular area of systems analysis around the world. The project has had good cooperation from those countries involved, and it is now coming to the point where the lessons learned from that opportunity are to be distilled and put in a form that many other people can benefit from.

In this way, I think that we are quite proud of the project's achievements and what they mean to us. We are very anxious to have your advice and suggestions as to how we can contribute and continue to build on that early success. Thank you very much.

Background of the Integrated Industrial Systems Project

Irving Lefkowitz

In follow-up to Dr. Levien's background of the Institute, I want to describe briefly the origins of the Integrated Industrial Systems Project, its goals, and the activities over the past year that have led up to the present Conference.

In the early meetings preceding the formation of IIASA, there were many discussions concerning the kinds of research activities that would be appropriate to the new Institute. One of the research areas that seemed to generate broad interest was the control of industrial systems. Accordingly, a research Planning Conference was held in October 1973 to discuss the proposal of a IIASA project in this area and to develop recommendations concerning its scope, objectives, and plans. The essential results of this Planning Conference were a set of recommendations that are summarized as follows:

1) IIASA should undertake a research study in the area of integrated control of industrial systems in that such a study would be consistent with the goals of IIASA and would have reasonable prospects for useful results.

2) The scope of the project should be restricted to the information processing, decision making, and control aspects of the problem. In particular, recognizing the limited resources that would be available to the project team, the study should not get involved in developing new technology or hardware.

3) The initial study should focus on a specific industry in order that the problems of real systems may be addressed and that the probability of results having only theoretical interest may be minimized.

4) Nevertheless, it was deemed important that the study be developed on a firm conceptual and methodological base so that the experiences with the specific study may lead to generalizations applicable to a suitably broad class of industrial systems. There was a strong concensus in the Conference for the multilevel, multilayer control hierarchy to provide the framework for such a conceptual base.

5) The steel industry was suggested as an appropriate vehicle for the first phase of the research project, to be followed by a candidate from the mechanical engineering industry, and finally by one from the chemical process industry. The overall goal proposed for the project was the development, as a result of these studies, of some general guidelines that would be useful in the structuring of the control and information system for achieving integration of the entire production system.

Active work on the Integrated Industrial Systems Project (IIS) began just about one year ago, on July 1, 1974, in fact. The team working on the steel study consisted of A. Cheliustkin (USSR) and I. Lefkowitz (USA), who served as co-leaders of the Project, along with D.H. Kelley (UK), B. Mazel (CSSR) and G. Surguchev (USSR).

The factors motivating systems integration include: increased operating efficiency and productivity, improved product quality, more effective utilization of resources (including considerations of energy, scarce materials, manpower, etc.), compliance with technological and environmental constraints (for example, ensuring satisfaction of pollution constraints on air and water effluents), adaptability to time varying conditions and system integrity. By this last point I mean the ability of the system to remain viable despite contingency events or major disturbances.

Now, why did we choose the steel industry for our first case study? In some respects, it was an arbitrary choice; however, there were a number of factors that influenced our decision. First, steel is a basic industry of general and universal interest. Second, it is a complex industry with a great variety of processing and technological components that stimulate a broad spectrum of systems problems of the kind that we wanted to consider. And finally, it was the industry that, in our judgment, was most advanced at the present time in the application of computerization and the integrated system approach.

Our next step was to carry out a state-of-the-art survey of computerization and integrated systems control in the steel industry. The purpose of the survey was to determine the "leading edge" of control technology around the world as currently applied to steel making, to identify people and information sources, and to identify problem areas and the limitations of current practice.

In the course of the survey, we visited some 35 companies and research institutes in 11 countries around the world. We prepared a preliminary draft report on this state-of-the-art survey which has been distributed to each of you. The report has also been sent to various participants of the survey who were not able to attend this Conference.

We emphasize the preliminary nature of this report because we want to incorporate in the final report feedback from you and others who are reviewing the draft version. Indeed, a major objective of this Conference we are now holding is to encourage this feedback so that we may use it in preparing the final report on the state-of-the-art survey.

Now, the steel study was the dominant activity of the IIS group over the past year; however, there were some other activities we were engaged in that I should mention. Dr. Levien has already referred to our participation in the survey on computer-aided design. This activity was led by Josef Hatvany who will participate in the discussions on Wednesday. We also expended considerable effort in the area of multilevel, multilayer hierarchical control, particularly with respect to the development of concepts and the relating of these concepts to our experiences in the steel study. Finally, we have done some exploratory work on the theme of the regional industrial complex--Dr. Levien has made reference to this as one of the main cross-cutting themes to be developed at IIASA. Our specific interest in this area relates to the role we might play as part of a collaborative effort involving other IIASA project groups as well as some external agencies (for example, UNEP and UNIDO), where we would be able to make effective inputs as a result of the concepts, methodologies, and experiences developed through this present project.

Common to all IIASA projects, the IIS project has had to operate under rather severe limitations with respect to personnel, time, and funding when measured against our objectives and ambitions for the program. There is no possibility of making sufficient progress without very active collaboration with external research groups and institutions. We had such collaboration in the steel study with: the Institute of Control Sciences and the Institute of Complex Automation, both in the Soviet Union; INORGA, an industrial research institute in the CSSR; and Purdue University in the United States--T. J. Williams will give a presentation of the activities of the Purdue group tomorrow. In addition, there were many external organizations that provided strong inputs to the project--British Steel Corporation, Japan Iron and Steel Federation, Vöest-Alpine Company in Austria--to mention a few. In the computer-aided design study, active collaboration took place with a number of institutions--the Computer and Automation Institute in Hungary; the National Engineering Laboratory in the UK; Control Data Corporation in the United States, and the International Federation for Information Processing (IFIP), (headquartered in Sweden). Again, a number of other organizations provided valuable inputs to the survey study.

I next want to give you an idea of the resources brought to bear on the project in terms of personnel. I have listed on Table 1 the people who have been associated with the IIS Project since July 1974, identifying their countries of origin, the nature of their professional backgrounds (distinguishing among research institute, university, or industry), and indicating the duration of their affiliation with the project to date. Table 1 also shows the relative distribution of activity of the project members expressed as man-months of effort in the different major areas.

We note from Table 1 that there is a fair distribution of the personnel by country, by geographic area, and with respect to professional background. Of the total effort expended to date approximately 54% went to research, 10% into the development and formulation of hierarchical control concepts, 15% into the industrial regional development study and about 21% into the computer-aided design area, including some work in preparation for the proposed second phase of the project--application of integrated control to a mechanical engineering type of industry.

Finally, I want to summarize our plans for the immediate future. First, of all, as I have just indicated, we want to issue a final state-of-the-art report on the steel survey based on both the preliminary report and the feedback resulting from this Conference and from various correspondents who were unable to attend. We will issue a Conference Proceedings along with the final report; these will be distributed as soon as they are ready.

We are also discussing plans for extension of the study of integrated systems control in application to a mechanical engineering system and, possibly following that, a chemical processing system. For the mechanical engineering study, we have a tentative proposal made by Josef Hatvany who will discuss it on Wednesday, briefly indicating what ideas are being developed in this direction. One of the objectives associated with this sequence of studies, the steel, the mechanical engineering, the chemical processing studies, is that these all represent different types of industrial systems and we would like to distill from these experiences some general guidelines that would provide for an integrated systems approach to industrial systems. Finally, there are prospects of our participating in a collaborative project with some of the other groups in a study concerned with developments of regional industrial complexes.

Let me now say just a few words regarding the format of the Conference. We will have a series of presentations by members of the IIS Project concerning the state-of-the-art survey; these presentations will follow the chapters of the preliminary report that you have. As I mentioned before, we are interested in your comments, critical views, and any additional inputs that you can bring to bear on the subject. We also have a number of invited talks that relate to activities or perspectives in complementary areas that are not covered by our survey report but that we think should be brought into the overall picture. We have arranged the schedule with frequent formal discussion periods in order to encourage interactive feedback and we hope that all of you will actively participate.

Table 1. Participants in the IIS Project over the period July 1974-July 1975.

Scientist	Country	Background	Time (months)	Activity in Man-Months			
				A	B	C	D
A. Cheliustkin*	USSR	Research Institute	12				
I. Lefkowitz*	USA	University	12				
J. Hatvany	Hungary	Research Institute					
D.H. Kelley	UK	Industry	12				
B. Mazel	CSSR	Research Institute					
G. Surguchev	USSR	Research Institute					
O. Bernadini	Italy	Industry					
H. Hubner	Austria	University					
J. Zander	GDR	Research Institute					
C. deVanssay	France	Industry					
K. Ito	Japan	University					

*Project co-leaders

Notes:

A-integrated systems control in steel making.

B-multilevel, hierarchical control approach.

C-computer-aided design survey/integrated systems control in mechanical engineering industry.

D-systems analysis applied to regional industrial complex.

Finally, we have scheduled a panel discussion for the last session which we hope will provide the basis for summarizing the feedback and finalizing the various views on the subjects being presented.

State-of-the-Art Review of Integrated Industrial Systems Control

I. Lefkowitz, A. Cheliustkin and D.H. Kelley

INTRODUCTION

Background of the Project

There has been a growing tendency in recent years for scientists around the world to conduct multidisciplinary studies of large scale systems. These studies embrace the whole spectrum of economic, technological, environmental, and social factors which characterize the complex problems of advanced industrial societies. In seaching for ways to cope with these problems, many scientists have turned to the methodological tools of applied systems analysis. An increasingly favorable international political situation has encouraged the hope of using this new approach in a context of supranational scientific collaboration. The International Institute for Applied Systems Analysis (IIASA) was founded in October 1972 as an expression of this hope.[1]

In early 1973, the IIASA Council proposed a number of broad subject areas of research which might be considered by the new Institute. One of the areas suggested was the automated control of industrial systems. A multinational conference of experts was held in October 1973 to discuss the proposed project area and to come up with specific recommendations for research goals, tasks, and guidelines. The results of these discussions were issued as a report;[2] briefly, they may be summarized as follows:

1) There was general agreement that systems analysis applied to industrial systems is an appropriate area for IIASA research in that a) it was of general interest to most member nations of IIASA, b) it was consistent with the stipulations of goals and objectives of the Charter of the Institute; c) research tasks could

---

[1] See the IIASA annual reports for information on the Institute.

[2] See the Proceedings of the IIASA Planning Conference on Automated Control of Industrial Systems PC-8 (International Institute for Applied Systems Analysis, Laxenburg, Austria, 1973)

be identified that were reasonable within the constraints of available resources at IIASA; and d) there were reasonable expectations that such efforts would produce useful results.

2) It was recommended that the project be oriented to the problem of systems integration of large-scale and complex industrial enterprises. The underlying motivation here is the achievement of maximum efficiency of production consistent with the various constraints that have to be satisfied (for example, environment, product quality, etc.)

3) In order to keep the study within manageable bounds, it was suggested that the scope of effort be restricted to the problems of integration of the information processing and decision-making system (for example, planning, scheduling, production control functions). In particular, problems of technology, plant design, process control, and the like were to be avoided except where they impinged directly on the problems of integration and coordination (for example, the interface of process control functions with production control functions, etc.)

4) The multilevel/multilayer hierarchical control approach was proposed as an appropriate conceptual basis on which to structure the system for information processing and decision making.

5) It was recommended that the project focus on a specific industry in its initial effort in order to avoid the prospect of coming up with highly theoretical and philosophical results that would be of only limited value in practical application. The iron and steel industry was suggested as a first candidate for study, to be followed by a mechanical engineering type system and perhaps a chemical processing type system.

General Goals of Integrated Systems Control

The traditional concept of control, in application to industrial process systems, concerns the problem of how to vary certain inputs to the system so that a) designated output variables are held at fixed values or made to follow predetermined time trajectories or b) the state vector of the system is transferred (optimally) from some initial value to a specified final value. However, there has been an increasing tendency to consider control from a broader and more general perspective. Strong contributing factors in this trend are:

1) the increasing application of computers in process control, providing the hardware and software means for implementing more sophisticated control concepts, and

2) the growing awareness and acceptance of a "systems approach" in the design and control of industrial process systems.

The objective of integrated systems control, in a very general sense, is to achieve the most efficient utilization of resources (for example, materials, energy, the environment, labor, capital) in the production of goods satisfying quality specifications and consistent with goals and constraints that may be imposed by society. Thus, integrated systems control is concerned with the broad spectrum of decision-making and control functions (for example, process control, operations control, scheduling, planning, etc.) that play a role in the effective operation of the system with respect to its production goals.

Performance of the processing system depends on a variety of factors including:

a) product specifications and process design;

b) the nature of resources available and environmental constraints;

c) the choice of processing conditions, allocation of resources, scheduling of operating sequences, etc.

Thus, we distinguish two phases of system evolution with respect to information processing and decision-making functions.

Design Phase

This phase concerns implementation of overall system objectives through the design of the production means. It is characterized generally by very long time horizons and by high costs for implementation (for example, analysis and design effort, capital investment). There is a variety of disturbances that affect the design process and hence can stimulate consideration of a design modification or even reinitiation of the design process. These include major changes in product specifications or quality requirements, technological developments with respect to a new product or a new method of production, equipment failure, major changes in resource availability, and the imposition of a new constraint (for example, stricter environmental standards, etc.).

Decisions at the design phase tend to be strongly conditioned by subjective and nonquantifiable factors; hence, the human traditionally plays a dominant role. Methods and techniques of computer-aided design are becoming increasingly important, however, in coupling the capabilities of the computer (rapid computation, handling of large data bases, fast-time simulation of the consequences of alternative policies, etc.) with the judgment, experience, and intuitive aspects of the design process to which the human designer makes the best contribution.

Operating Phase

Here decisions and control actions have to do with determining operating conditions, throughput rates, sequencing of operations, etc., so that product specifications are satisfied along with the constraints imposed by environmental interactions, technological factors, etc. Further considerations may then include the optimization of performance with respect to production efficiency, utilization of resources, etc.

As we can see, the decision-making and control functions tend to be:

1) continuing and repetitive and based on real-time processing of information;

2) strongly conditioned by feedbacks that describe the present state of the system and the results of prior operating experiences;

3) based on technologically oriented deterministic models that lend themselves to computer-implemented algorithms.

Further, the decision-making processes cover time scales ranging from very short span control operations to long-range planning processes.

The decision-making and control actions are carried out in a system that is evolving in real time; hence, they must respond to the effects of:

a) variations in input conditions (for example, changes in product demand, order sequence, raw material composition);

b) time-varying characteristics of processing units (for example, fouling of heat transfer surfaces);

c) changes in the objective function owing to economic factors, environmental constraints, etc.;

d) errors and inadequacies of the models used in determining the decisions and control actions.

We note that the boundary separating the design and operating phases of the evolution of the system may not be sharp and, indeed, aspects of long-range planning associated with the operation of the system may well imbed aspects of the design functions, for example, replacement of a production unit or modification of a process design. Further, there is a strong coupling between plant design and operation, and in order to achieve the maximum overall performance of the system, these interactions and the related trade-off factors must be appropriately considered.

Hierarchical Control Approach

Industrial systems are characteristically large, complex, and time varying; hence, the solution of the overall problem considered above is extremely difficult if not infeasible with existing analytical and computational capabilities. Consequently, current practice tends toward empirical and suboptimal solutions to locally defined problems with perhaps only an ad hoc procedure for their integration and coordination.

The multilevel and multilayer hierarchical structuring of the decision-making and control system is considered as the basic approach to handling the overall problem. The approach embodies the following features:

1) The complex system is decomposed into a number of coupled subsystems, each with its own set of decision-making and control functions based on local criteria and on local information sets. Because of subsystem interactions, it is necessary to coordinate the objectives/ actions of the local controllers to make them consistent with overall system objectives and constraints.

2) The overall system decision-making and control problem is decomposed into a set of subproblems, each with its own objective function, model, constraint set, etc. These subproblems are generally distinguished with respect to time scale (for example, planning, scheduling, and control functions). Since the subproblems essentially interact, for example, the solution of the planning problem affects the scheduling problem, integration of the subproblems is necessary to ensure satisfaction of objectives and constraints associated with the overall system.

3) The complex system relationships are approximated by simplified and aggregated models corresponding to each stage and level of decision making. This is necessary in consideration of the costs associated with model development, on-line computations, etc. Further, since industrial systems are characteristically time varying (aging of components, etc.), subject to a variety of

continually varying inputs, and also subject to more or less frequent contingency occurrences (for example, equipment breakdown, emergency order), the incorporation of means for on-line updating of the models through feedback of relevant data and experience indicators is an essential feature of the information system.

Scope of the Current Study and Mode of Operations

The steel making industry was selected as the first system for a case study of the integrated systems approach. There were several reasons for this choice. First, steel is a basic industry and of direct interest to most of the countries supporting IIASA. Second, it is a very complex industry with a wide variety of different types of processing and manufacturing facilities and, hence, rich in the broad spectrum of systems problems likely to be encountered in industrial applications. Third, and most important, the steel industry represents, at the present time, perhaps the most advanced area of technology with respect to the application of an integrated systems approach and in the application of computers for real-time information processing and decision making. Thus, it was felt that the steel industry provided a good base to start our investigation.

Having settled on steel making, the next step was to carry out a "state-of-the-art" survey based on information in the literature, plant visits and discussions with various experts in the field. Among the objectives of the survey were:

a) determining the "leading edge" of current planning, scheduling, and production control functions and their integration as practiced in advanced steelworks around the world;

b) identifying problem areas and limitations inherent in current practices; and

c) identifying people and information sources (for example, simulation models) that may be useful in the further development of the project.

The results of the survey are presented in this State-of-the-Art Review[3]. The Review attempts to identify <u>what</u> are the most advanced practices in planning, scheduling, and production control, and <u>how</u> these are implemented and coordinated to achieve

---

[3] A preliminary draft of this Review was issued in June 1975 as a IIASA internal paper; its purpose was to provide a background of source material for the IIASA Conference on Integrated Systems Control in the Steel Industry held June 30-July 2, 1975, in Laxenburg.

systems integration. However, the Review is not concerned with the cataloguing of the current state of these practices according to company, country or society; hence, there is no attempt to identify who is doing what, except as the identification may be relevant to the discussion at hand. Also, the Review avoids discussion of specific hardware used in the various advanced systems referred to, or of the technological models, scheduling algorithms, process control functions, and related details. These are all very important factors that enter into the ultimate realization of a working system; however, they were considered (for various practical reasons) to be outside the scope of the present study.

Besides describing the results of the state-of-the-art survey, and providing an interpretation of our observations, this Review presents a formalization of the multilevel/multilayer hierarchical control approach oriented to the problem of integration of complex industrial systems. The approach reflects a number of modifications of the hierarchical structuring of the decision-making and control system, motivated by some of the experiences gained from the steel study.

The objective, ultimately, is to develop a conceptual framework for design of integrated control of industrial systems that will lead to the formulation of general guidelines applicable to a broad class of industrial systems. The results of the steel industry study will provide the initial background experience for assessing the effectiveness (and limitations) of the proposed hierarchical approach. Further case studies based on a mechanical engineering type system, for example discrete manufacturing), and, finally, perhaps a chemical processing system, should then broaden the base upon which the general guidelines are validated.

Organization of the Review

Following this introductory section, a general review of the advanced practice of integrated systems control in the steel industry is then presented. The emphasis is on the descriptive aspects of the state-of-the-art survey, organized according to the planning, scheduling, and operations levels of the decision-making hierarchy.

The next section attempts to develop some of the concepts and analytical tools that will be useful for formulating general guidelines for integrated control of industrial systems. The specific focus of the section is on the multilevel/multilayer hierarchical control approach which is illustrated through references to various examples taken from steel making practice.

Another section presents some generalizations and aspects of various experiences of the steel study. For example, motivating factors for steelworks integration are discussed, and the salient features of the observations described earlier are summarized.

The final section presents a summary of results, conclusions, and recommendations for further study. This section reflects some of the results the Conference discussions, as well as feedback prompted by the preliminary draft report of the state-of-the-art survey.

A REVIEW OF INDUSTRIAL SYSTEMS CONTROL IN THE STEEL INDUSTRY

Introduction

A modern integrated steelworks represents an extremely large capital investment; a plant with an annual capacity of five million tons of steel could cost about $5 billion if built from scratch at 1974 prices. The number of people involved in such a plant greatly depends on the capacity of the technological equipment, its organizational structure, the level of automation of the production processes, and the level of computerization of the management information processes.

In some steelworks, the productivity per employee reaches 750-800 tons of steel per year; in others it is only about 200-300 tons. There is a tendency to use equipment of increasingly high capacity. Thus, in 1960, blast furnaces of 10 meter hearth diameter and a capacity of some 1.2 million tons/year were installed for the production of iron. Nowadays, blast furnaces with hearth diameters of 14 meters and capacities of over 3 million tons/year are being constructed. In 1962, oxygen-blown furnaces of some 150 tons capacity were used for the production of crude steel. At present, oxygen-blown furnaces for heat weights of over 400 tons are in operation. In 1960 the transformer rating of electric arc furnaces averaged some 350 kVA/tons. Now, electric arc furnaces with transformer ratings of over 600 kVA/ton are in operation.

The capacity of rolling mills has greatly increased owing to the use of higher rolling speeds (up to 60 meters/sec for the wirerod mills and up to 35 meters/sec for strip mills), use of larger weight ingots, slabs, blooms and billets. There also has been a trend toward increasing the total production capacity of steelworks (up to 20-30 million tons annually).

Many other industries that rely on the use of steel in some shape or form, for example, for buildings, plant, equipment, machinery, tools and transportation, may be located near the steelworks. Thus, in many cases the steelworks becomes a center of the industrialized region with populations ranging from 50,000 to several hundred thousand.

Living conditions in the communities located in this area depend very much on the kind of pollution control exercised by the steelworks and other industries of the region. The effectiveness of this control also influences the geographical location of the settlements and their investment costs.

In some countries, all steel making plants are nationalized and all the normal business functions relating to running such plants are carried out in strict accordance with government policy. These countries have a national plan embracing all manufacturing industries and the types and quantities of steel required over a specified period are stated as part of the plan.

At the other extreme, some steel companies are financed completely by private capital and are run as profit motivated businesses. Such steel companies, in what can be described as "market oriented" economies, must make their own estimates of the steel demand and plan their capacity and operations accordingly. In these situations, there are normally competing companies and so the problem of estimating demand for each company's products is further complicated by the need to decide what share of the potential market it is realistic to assume can be captured.

Plans

It is commonplace to hear the word "planning" used to describe a wide variety of activities, each with different objectives, relating to different time scales and involving different degrees of detail. The word "plan" often refers to a statement of intentions based on, and conditional upon, a given set of assumptions. The longer the time scale involved and the larger the number of factors that have been predicted or forecast, the higher is the chance that the plan will be modified before implementation.

Objectives

Planning objectives themselves vary a great deal depending on purpose. Some are general policy decisions and some are basically targets which are usually employed in sales situations or simple manufacturing activities where speed of working does not affect quality and time is a critical resource.

In the context of this report the majority of plans are, as previously mentioned, statements of intent and as such the objective is to ensure that all factions of an enterprise know what to expect, at what time, and what actions to take. It provides the guidelines necessary to help lower level decision makers to take actions consistent with overall goals. The level of detail can range from extremely fine to very general, again depending on the situation and purpose.

Plant Loading

Production planning on an annual time scale is usually based completely on a forecast of demand. By the time quarterly production planning takes place it is likely that some, but by no means all, orders are known. Plant loading is the allocation of demand to production units for processing during some specified period, which could be a month or a week, for example. Loading can be undertaken using a forecast of orders but, in general, the receipt of an order initiates the loading activity. The final result of the plant loading is a detailed production plan, that is, a statement of all the items to be processed at a given department or shop, for example, a rolling mill, during a given production period.

Scheduling

The production plan is divided into parts corresponding to shorter time intervals, for example, a week or a day. The plant loading is transformed into a definite list of items in the processing sequence, considering the time required for each operation, the capacities of equipment, order due dates, etc. This becomes the production schedule which is the key document for coordinating activities at the operations control level.

In compiling the production schedule, the technological constraints have to be considered. For instance, the hot strip mill operation gives rise to constraints that considerably limit the sequencing choices. On top of this, constraints induced by the relative urgency of order items and constraints dictated by the needs of adjacent processes severely limit the options. Frequently the problem is not simply one of selecting the "best" of a number of feasible solutions but rather one of knowing which rules to bend and which constraints to relax so as to get a feasible solution, one that still can be called the "best" feasible solution.

The Planning Hierarchy

Timing is one of the critical parameters of planning, loading, and scheduling. In many ways, progress from the longest term planning through to detailed production scheduling can be thought of as a continuous process in which the degree of detail that it is both practical and sensible to work in increases as the period covered shortens. Since at any particular stage there is a limit to the reliability of data and to the amount of detail available, there is little point in producing plans or schedules in any more detail than the accuracy of the input data permits.

This conceptually continuous spectrum of planning is divided into definite manageable stages of discrete planning horizons in a formalization of the whole planning procedure. Plans are developed from one time horizon to the next when either timing or the availability of further information or the occurrence of events demands that further plans be determined. Below are given planning horizons most frequently found in the companies visited, and Figure 1 illustrates the main relationships involved in the planning, scheduling and handling of orders.

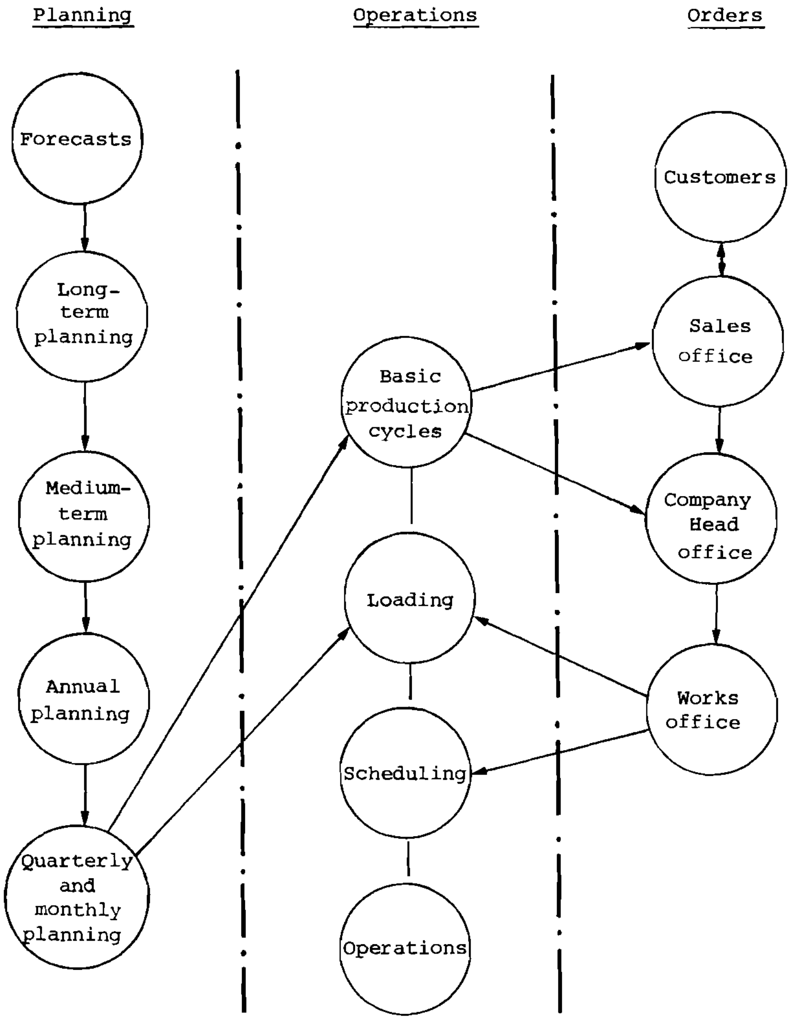


Figure 1. Main planning, scheduling and order processing relationships.

Long-, medium-, and annual-term planning are based mostly on forecasts. This planning considers the company's available resources and is done by the company's head office. Only the detailed planning based on received orders is done by the steelworks.

1) Long-Term Planning

The long-term plan usually covers a time horizon of 10 to 20 years. It is of necessity almost completely based on forecasts and is intended to guide thinking concerning the general direction of a company's policy. Where it is prudent to make long-term contracts for, say, raw materials or to accept long-term order commitments, these become constraints in the years to come. Only time can tell whether these were good or bad commitments. A complete new integrated steelworks can take from five to eight years to design and to build up to working capacity; as such, the decision to invest on this scale must be taken in the context of long-term planning.

2) Medium-Term Planning

The medium-term plan usually covers a period of from one to five years. Over this type of time horizon the major changes in productive capacity are known and so that emphasis is on making profitable use of the known capacity. Effective capacity can be adjusted within certain limits by working more or fewer shifts and some units can be shut down for a period (a virtue can be made out of this situation by devoting the surplus units and personnel to major maintenance activities). In general, it is the product demand that is the major unknown. followed closely by the costs of raw materials, labor, etc., and the price that can be realized for the finished products. Both long- and medium-term planning can be considered as strategic.

3) Annual Planning

Planning for "next year" often seems to be the turning point between strategic and tactical planning. There are still a number of unknowns but annual contracts must be negotiated and the lead time for recruiting labor, planning major maintenance operations, etc., is a few months. In practice, therefore, the most detailed planning seems to start on the annual basis. Much attention is paid to costs, productivity levels, sales forecasts or annual production allotments, etc., and as a result, the year is mapped out in terms of raw material purchases, expected production requirements, production capacity, budgets, personnel requirements, and so on. Annual plans are frequently broken down into four quarters at this stage and sometimes into months.

4) Quarterly Planning

Quarterly planning is usually the first step in turning a basically predicted plan into one based on real production demands. It also represents an opportunity for adjusting any details of the annual plan which must be modified in the light of changing circumstances. Otherwise, apart from perhaps including some production loading, the form and purpose of the quarterly plan is much the same as the annual plan.

5) Monthly Planning

At the monthly planning stage, production planning, especially order processing and plant loading, begins in earnest and to a large extent everything is based on actual orders. Schedules as such, that is, detailed item sequences, are not normally started at this time scale although there are exceptions.

6) One Week or 10 Day Scheduling

Breaking the monthly plan into the shorter time assignments leads to the production schedule. The majority of companies produce schedules on a weekly basis since a high percentage of the orders are definite and realistic scheduling can be undertaken. In some steelworks with computerized control systems, a 10 day base for scheduling is used instead of seven days because of increased confidence in performance to specifications. Some indications of a daily breakdown are often shown in conjunction with the weekly or 10 day schedule. Again there is the opportunity to adjust previously laid plans if actual events warrant some change.

7) Daily and Shift Scheduling

The daily schedule is usually an updated version of the weekly plan with any changes or adjustments effected that may have been caused by an earlier failure to keep to schedule or by the hurried rescheduling of urgent items. The division of the daily schedule into shift schedules is rarely explicit. Each shift makes as much progress as it can and the next shift takes over according to time.

Long-Term Planning

The management of any business concern must face up to its objectives and determine its basic policies. The freedom of choice of the objectives is usually broader for a private company than for nationalized ventures. The private company is also likely to have grown and developed from small beginnings and its objectives may have been modified on several occasions especially as each major development decision was faced. Nationalized industries on the other hand are likely to start life as vast concerns comprising a heterogeneous collection of existing ventures. Some act of a parliament or government law may well define all the relevant guidelines, and management's task is to run the concern satisfactorily within these guidelines. The main end product of the long-term stage is clearly a set of statements, covering all aspects of a company's activities, for example, products, plant, equipment, supplies, personnel, finance, marketing, development, research, social policy.

Private and nationalized concerns must be considered separately. All the nationalized concerns visited have some form of government bill or charter of law that spells out the purposes, objectives, and constraints. Many of the statements are of a political nature and phrases of the type: "meeting the country's demand at minimum cost" and "all developments must be considered in the light of their sociological and environmental consequences" are commonplace.

Private companies were very reticent to talk about their own formal strategic policy documents and certainly unhappy about divulging the contents to anybody outside the company. But it is clear that many reviewed their long-term strategies in some depth on an annual basis as opposed to specific long-term planning.

Although data may be hard to come by and many factors defy scientific analysis, companies do use models for building up costs, cash flows, and discounting. One complete financial-plus-production model located was used to test out the validity of a new venture under many different scenarios. Factors such as product mix, costs, prices, equipment configuration were all "flexed" and although the model itself contained no optimizing mechanisms, the man/computer interplay was instrumental in arriving at a robust solution.

It is interesting to note that the comprehensive model referred to above was used <u>only</u> during the strategy formulation stage and has not been used at all since. The company employs extensive models for long-term and shorter term planning but these are tailor-made for each task. The main difference between the strategic and long-term models are:

a) The strategic model was built to include extensive facilities for varying all parameters over wide ranges. Such facilities are not needed to the same extent for long-term planning.

b) The product groupings, cost structure, and the description of production facilities were all needed to different degrees of detail in the two models. For example, the products to be made at the new

> plant were completely flexible in the strategic model but "limited" in the long range model by existing and planned plant configurations.

Many companies do not make a firm division between this strategy stage and long-term planning and it can be argued that any such division is artificial or forced. However, enough cases exist where the difference is clear to justify a separate classification in this review.

By far the majority of companies visited considered long-term planning to cover a 10 year period. Some claimed to consider longer periods but not as a formal extension of the 10 year plans. A common view was that if any discounted financial appraisals were undertaken, the years in excess of 10 made a minimal contribution to present value.

The long-term planning horizon is closely connected with the capital plant depreciation period. The two periods commonly are 10 or 15 years, with the former sometimes favored even by those actually using the latter. Arguments for using the shorter period are often based on a fear that the company may find it difficult to adapt to new processes and technologies if too high a capital value is placed on existing plant.

Long-term planning is a complex process and less easily structured compared to a very short-term planning operation. With so many unknowns and every facit seen as dependent on another, or at least strongly interactive with others, there is not an absolute starting point. Figure 2 shows an attempt to provide a workable structure and dependence tree. It is a gross simplification, and in practice, many feedback loops exist inside the main loop as shown and many less formal links exist. For example, the sales plan will be initially drawn up with a very good idea of what production capabilities, both type and quality, will or could exist over the period and devisors of the plant development plan will know within reasonable limits the amount of capital that the company would be able to invest in new plants.

Forecasting Economic Growth

The demand for steel arises out of many activities, for example, capital projects such as new buildings and bridges; consumer goods such as motor cars and washing machines; and disposable items like cans and paper clips. A country's economic position will influence the demand for such different classes of steel products and any attempt to make demand forecasts for a steel company would be well advised to take a view of the economic situation over the period in question.

This is in fact done by a number of steel companies, as often as not in conjunction with other bodies such as government departments and universities. Models do exist that, while

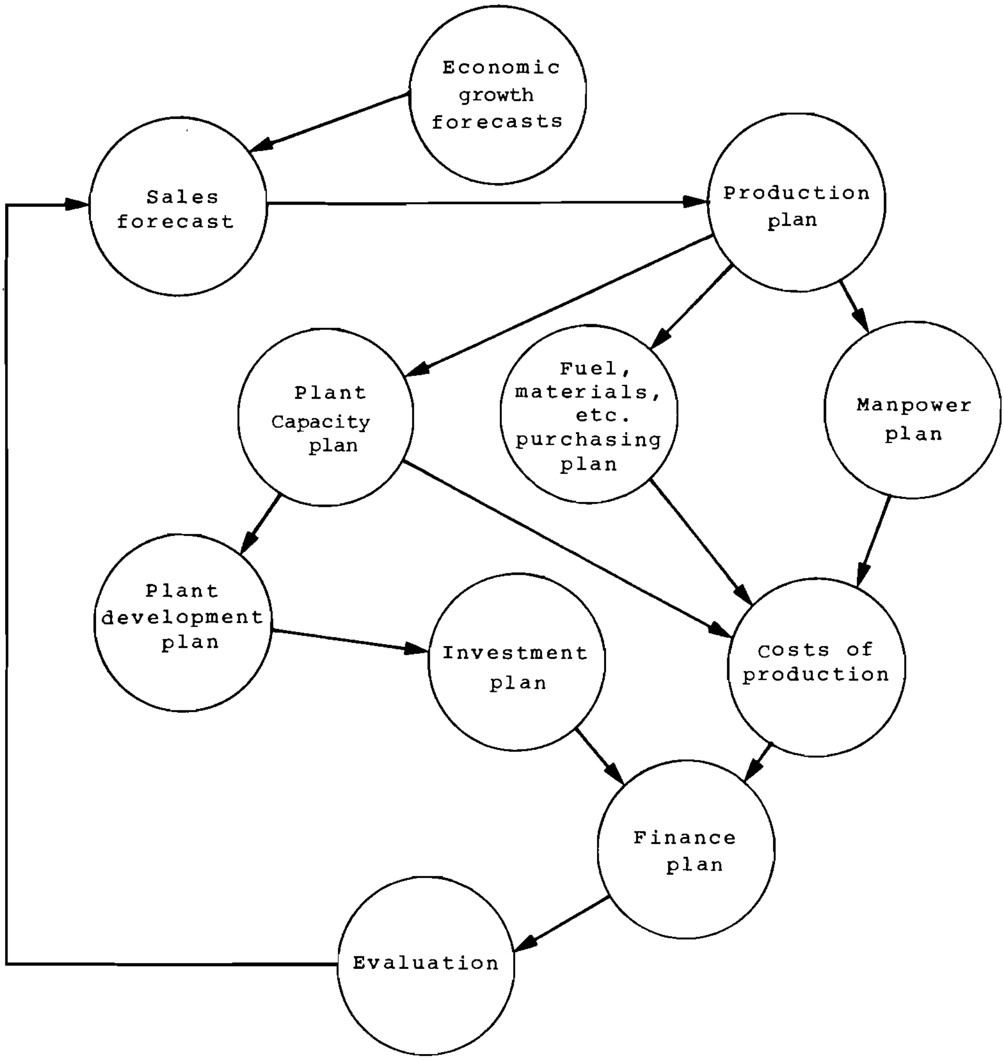


Figure 2. Long-term planning: main components and relationships.

certainly not perfect, do go a long way in helping to form a reasoned view. The fact that no details were made available together with an obvious satisfaction with the contribution made, suggests that such models are not the full answer but are worthwhile.

Sales Plan

A company is not viable without orders, and there is some logic in starting the planning cycle by considering how much of which products could be sold over the given period. Every company visited has some form of model used to forecast demand. The simplest are statistical extrapolation models that exploit any detectable trends and cycles while predicting the future. General opinion suggests that this approach is useful, but, quite naturally, it does not predict any basic changes in direction. Thus, most companies use such methods to provide one of a number of viewpoints to be taken into consideration.

Most companies also build up a total demand forecast by breaking down their sales outlets 1) geographically, 2) by product, and 3) by user. This approach allows individual and detailed trends to be sought and projected. Any known discontinuities, for example, the start of a major shipbuilding program or, equally, the cancellation of a large contract, can be included in the reckoning at this stage. It is at this level that use can be made of the national economic forecasts previously mentioned.

It is common to find that all functions within a steel company that have any view at all on sales levels are encouraged to put forward an assessment of likely trends. It is a senior management level that attempts to resolve the host of conflicting advice that results, and the marketing or sales function has prime responsibility.

Where a strong competitive marketing situation exists, the above procedures are first arrived at over the full market, that is to say, the combined market of all competing firms. Then a further level of uncertainty comes, namely, how much of the total potential market can the one steel company reasonably plan to attract as firm orders? At this level, there seems to be little that can be called a scientific analysis. The procedure usually consists of making assumptions, working out some of the consequences and assessing the outcome. The assumptions may then be adjusted depending on the view taken of the likely consequences. It can be argued that this conforms to the "true scientific method", namely, hypothesis, test, evaluate and reconsider the hypothesis; perhaps only the tests and evaluations are less than precise.

Whatever methods are used, the end result is a plan of expected sales by product by year, and as such represents a ten year demand on production. The next step is to consider if and how the production function can meet the demand.

Production Plan

Those responsible for long-term production plans will be aware of the combined capacities of all the company's works. They will also be aware of any already committed developments in terms of capability, capacity, and timing. The task, therefore, boils down to deciding how to allocate the sales plan elements to the available production facilities.

Many factors must be taken into account, for example, transport costs, production costs, minimum cost product balances, and the objective will be to calculate a plan that minimizes the total cost of producing the required products. This sounds like a natural computer application since just about everything can be quantified. In fact nearly all companies visited do have such an allocation program, but the permutations and combinations are so enormous and the constraints so complex that fully automatic optimizing facilities are not possible. Many programs include some optimizing sections, but interaction with manual planning is necessary. A sound evaluation of whatever plan results is the main outcome.

Success or failure in allocating the sales plan will indicate whether or not there is too much, adequate, or too little production capacity to accommodate economically the plan year by year. If there is over-capacity in some period, alternative strategies include shutting down departments, delaying any projects designed to increase relevant capacity, suggesting that the marketing and sales functions should explore further markets. The discovery that capacity is adequate must happen sometimes but the occasions seem rare. If under-capacity is detected, it will mean that some specific extra plant is needed, perhaps another steel making furnace or rolling mill. In a similar way, the production plan determines raw materials, fuels, manpower, etc., that are needed if the plan, as it stands, is to be implemented.

Plant Development Plan

All works review the suitability of existing equipment vis-à-vis their needs at regular intervals and some replacement or extension projects will nearly always be under consideration. The engineering departments are usually responsible once a specific project has been agreed upon, but, before that, they will be expected to work together with production staff and specialists (for example, operations research) in order to define the most suitable design. "Suitable" includes the implication of economic as well as technically competent.

A wide range of programs are available in most companies for technical calculations, project cash flow prediction, and simulation studies. All such programs provide assistance in arriving at a reasoned solution to the development plan. The final development plan will comprise those projects necessary to match the production plan and, in financial terms, constitutes an input to the investment plan.

The Investment Plan

As shown, the only input to the investment plan is from the plant development plan. In practice, however, there may well be other inputs, for example, investment in associated companies, office buildings, iron ore mining ventures. Summed together, the effect is a time task showing at which point in time given sums of money will be required. As such the investment plan becomes a demand on the company's cash flow. Programs which facilitate the calculations involved are commonplace and have few remarkable features.

Purchasing Plan

It is normal for supplies of major raw materials, for example, iron ore, to be secured by means of long-term contracts. For this reason, a long-term purchasing plan that reflects the demand implied in the production plan is essential.

The task is not as straightforward as might be assumed since the alternatives can be numerous and selecting the considered best strategy may involve much thought and calculation. For example, the requirement for iron ore may be met in several ways with different proportions of various ores at different prices. Linear programming routines are used to select minimum cost combinations and so guide the contract negotiations. The many problems of choosing wise financial arrangements as opposed to unsound ones cannot be solved by computer, but, again, the technique of using evaluation routines speeds up the process and allows more time for thought.

Manpower Plan

Not every company tackles manpower planning with the same dedication as, for example, plant capacity planning. However, companies do calculate manpower requirements over the long-term, taking into account growth, process development, age distributions, training times, and current skills. Some computer programs exist to carry out the calculations and the end result guides recruiting and training programs.

Cost of Production

The sales plan has been turned successively into a production plan, investment plan, material purchasing plan, and manpower plan. Each plan involves costs and it is necessary to calculate the overall cost, year by year, of fulfilling the sales plan in the manner so far selected.

All the usual problems of costing and cost allocating are encountered; this is a normal challenge to cost accountants. From a systems viewpoint, once the policies have been clarified, the calculations are tedious but not overly difficult. Most companies are heavily computerized in this area, and many cost build-up and allocation routines are in regular use.

Finance Plan

Demands for cash have now been built up from several sources, and it is necessary for a company to examine its overall position. Not only must the anticipated activities, sales, investment, production, etc. show an overall profit, but the company's ongoing cash flow also must be feasible. Computer programs exist that calculate the cash flow throughout a given period and indicate any shortfall or surplus over each subperiod.

Knowing the cash position is one thing, deciding what to do about temporary surpluses and shortages is another. In general, there are a finite number of financing possibilities, each with different terms, amounts and interest rates. Because the interest payments themselves generate further cash flows, both in and out, programs exist which seek the minimum cost/maximum profit solution.

Evaluation

The components of long-term planning have been described at some length and mention has been made of the numerous interdependency relationships between the individual plans. If planning is looked at in a pedantic, step by step manner, the final task is to review the overall financial position, that is, income, costs, capital required, interest, and take a view about the position's feasibility and desirability. In other words, this is a managerial check on credibility.

In practice, the process is rarely, if ever, considered satisfactory the first time through. It is likely that each element of the plan has been biased by an individual's optimism, pessimism, or even deliberate attempt to overstate the case in the hope of being forced back to where he really wanted to be anyway. So the evaluation may well conclude that the investment program is too costly and must be cut by x%. Everyone involved must calculate or take advice as to how the cut will affect his own area of responsibility and replan accordingly. The merry-go-round can then start all over again and may be reiterated several times.

If too many iterations are called for, the sheer volume of work will defeat a manually handled system, time will run out, and a "best guess" solution may well be adopted. Even with the computer routines to carry the bulk of the calculation load, the procedure is lengthy and tedious.

Several companies have attempted to build a computer-based system that incorporates all the major computational components into one system. One or two such systems are claimed to be satisfactory but no one yet claims to have developed the ultimate. Figure 3 shows the broad outline of such systems. The sales forecasts are manually determined with or without computer assistance. Likewise, the plant characteristics and standard costs are determined. The loading stage is not fully optimal. but some attempts are made to select the most economic routes whenever feasible. Management still needs to examine the results and generate alternative strategies by changing costs, sales forecasts, or plant capacities. Such a system enables alternative plant development and marketing strategies to be evaluated.

Action

Long-term planning activities absorb much company effort, both human and computer. The result is a clarification of a company's direction over the 10 year period, and it provides a reasoned framework within which decisions may be made at some later time. In general, the exercise is repeated each year when a further year is added to the far horizon and the most imminent year becomes a reality.

The main action that comes from the exercise is to place long-term contracts for raw materials, etc., and to initiate the longer-term plant building or extension projects. Ten years ahead is none too soon to start planning a venture that could take seven or eight years to implement. Apart from such types of decisions, not a great deal is irrevocably committed since there will still be time to adjust, for example, the timing of projects. Only negative decisions may be regretted if realization of a mistake comes too late for a missed opportunity to be salvaged.

Medium-Term Planning

Long-term planning determines strategies; policies are implemented as time goes by. Some of the companies visited think that they work through the long-term plans in sufficient detail, revised annually, to guide all necessary decision making up to a year or so ahead of real time. Thus all matters that take place on more than an annual time scale (this includes plant construction and exploring new markets) are decided as an integral part of the 10 year horizon plans.

Those companies that do not consider their long-term planning to be sufficiently refined, for example, on the question of detailed costs or the timing of major developments, take a more careful look at the first five years (three years in one case only) once a year. The basic approach to medium-term

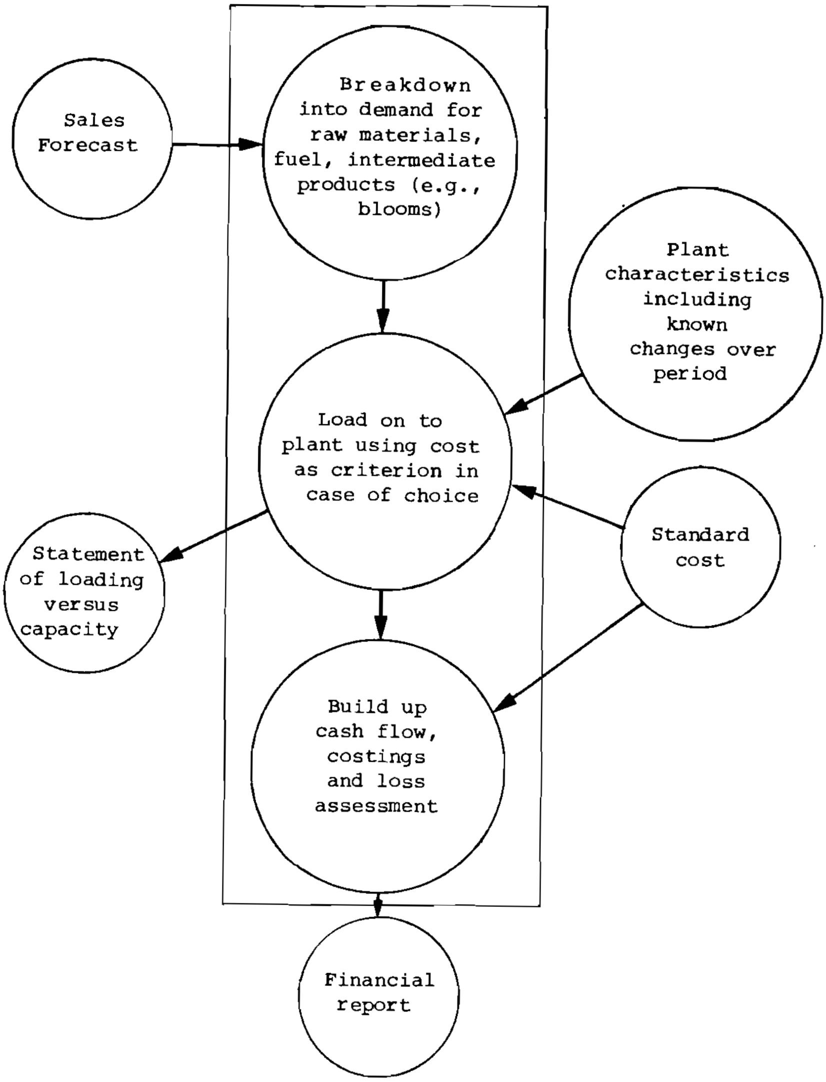


Figure 3. Long-term planning evaluation system.

planning is the same as for long-term planning except for the level of detail. Essentially, the same topics are covered, the main difference being that there is less flexibility of choice.

Annual Planning

As a result of long-term plans, plant capacity will by now be determined and, apart from the small changes in working capacity that can be brought about by working more or less hours, the available capacity becomes a constraint. Similarly, it may be possible to make some adjustments to the contracted quantities of raw materials such as iron ore and fuel, but this will normally be difficult and costly. The available raw materials therefore become another constraint.

All planning activities at this stage still rely on a demand forecast to provide the main motivation. Since time has passed and it is now much nearer to the time when actual orders should arrive, there will be much better information about trends etc. than when considering a 10 year cycle, but forecasts are still liable to be wrong. Figure 4 shows the main stages and relationships of a typical annual planning system in use today.

Sales Planning

With the longer-term sales plans as background and the knowledge as to how these plans have stood the test of practice over previous years, the marketing and sales functions are in a position to refine their forecasts. On the longer time scale models, statistical methods are used to guide demand forecasts; such methods are even more in evidence on the annual time scale. Detailed analyses of factors like demand by customer, sales outlet, industry, geographical area are compiled using models, and the resulting augmentation of estimates provided the basis (often full of contradictions) for manual determination of the sales forecast. The process involves much man/computer interaction and the procedure can cycle several times before the results home in on a state which can be pronounced acceptable. The sales plan arrived at this stage is still far from being in its final form although major changes are not normally expected.

Sales: Production Allocation Simulation

The next step is to accept the sales plan for the time being, and attempt to determine, through computer simulation, how the plan would be loaded on to the company's plants and how the plants would perform under the assigned loading. The basic idea is to restrict all mistakes to the computer medium where no harm is done, and to learn from such mistakes by the time the plan has to become reality.

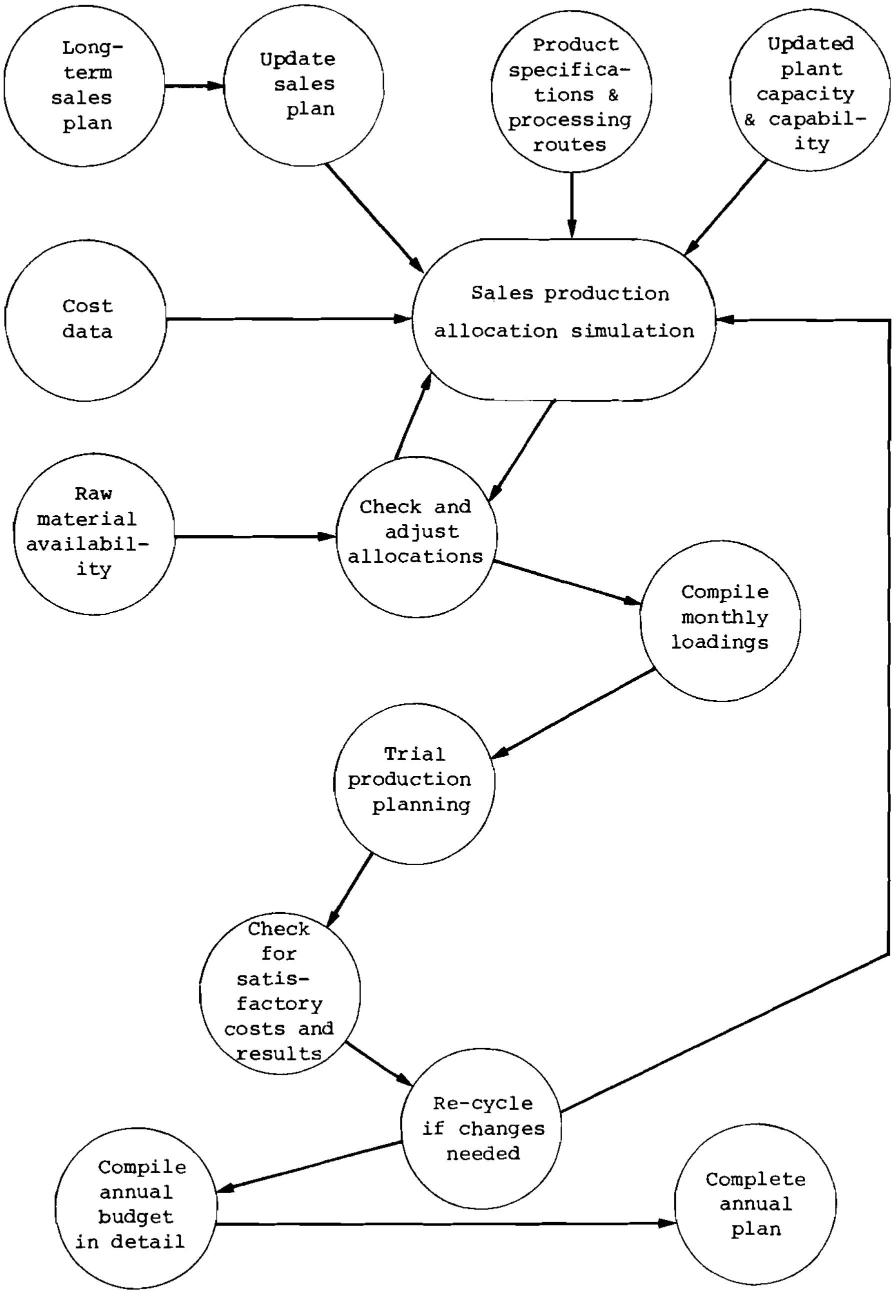


Figure 4. Main stages of annual planning.

The major inputs are the sales plan itself, an up-to-date statement of plant capacities and capabilities, cost information which can be used to select minimum cost routes or at least indicate any penalty for taking nonoptimum routes, and enough detail about such things as product characteristics, intermediate products, yields, and processing routes to enable a carefully considered loading to be meaningful. As a generalization, the simulations are not self-optimizing, but rather work on a heuristic (trial and assessment) basis.

The first stage is usually to load the expected orders onto the most obvious plant, taking into account plant capabilities and costs and other items when significant, for example, works-to-customer transport costs. Such a process causes no problems initially, that is, when there is adequate uncommitted capacity in the "favored" processes. Eventually, of course, the loading becomes tighter and the difficulty of selecting the "best" allocation increases. Toward the end of the process some positively undesirable allocation will be made and perhaps some orders will be left unallocated.

A complete process of reviewing, adjusting, and reallocation then commences. In the first instance, the trial allocation will be costed and steps taken to improve any high cost sections. In general, this stage is not automatic and is in the form of man/computer interaction.

Several interesting programs for optimizing subsections of this allocation procedure are in use. For example, a company with several steel making shops of different capabilities and at different locations, faces a specific demand for steel. How best can this demand be allocated to the various shops? This question is answered by men as of such a submodel and after it has "done its best" the effect on other aspects of production must be reassessed. A more common form of subsystem optimization covers the allocation of raw materials, this is mainly achieved by linear programming.

Eventually, the allocation, costings, etc., are deemed to be satisfactory, or at least the best that can be determined. This decision, quite naturally, is a human judgment.

Trial Monthly Loadings and Production Plans

Following the simulation theme, the outcome of the allocation trials is a production demand that could well arise in practice. How then would it look if followed through? The first operation is to divide up the annual allocations into monthly allocations, process by process. Assuming a division into months is achieved, perhaps by several iterations, the next step is to hand the 12 monthly demands over to the production planning function for an opinion on feasibility. At the same time, cost accountants liaising with the planners, assess the monthly plans to ensure that they are both workable and economic. Any unacceptable aspects can cause the whole plan to be thrown back to the sales-production allocation simulation.

Annual Budget

Doubtless the above procedure could cycle forever but, since it is a manually controlled process, eventually a complete and sensible plan emerges. At this stage in most companies, the plan is presented to a top level management committee whose members are predominately production and technically oriented. Assuming agreement is forthcoming, the final stages in the annual planning procedures are to formalize the decision taken.

The monthly production plans are well developed as a result of the trial planning exercise so it remains to calculate a detailed company budget covering all operations and activities over the 12 month period. Although a lengthy process, it is a fairly straightforward procedure with computer assistance.

Complete Annual Plan

All this work and effort results in a detailed plan for all of the company's functions. A sales plan is ratified, a production plan exists and a budget for all activities has been laid down. In several companies the total is called the "Annual Operations Plan". Especially in large organizations (a single steel plant may employ 20,000 people), decisions must be made everyday at many levels, and it is impossible to involve everyone who is likely to be affected in all such detailed decision making. The annual plan is the vehicle by means of which everyone knows of the overall company objectives, especially in the way they are to be interpreted during the given year, and decision makers can in consequence act within the correct limits and in the planned direction. With the budget as a further guide, money can be committed and spent, within the limits of the budget and for specified purposes, without time consuming ad hoc discussions.

Comparison With Longer-Term Planning

To reiterate, all plans of 12 months and longer are based on forecasts and estimates, but the details and accuracy can be greater over the shorter periods. Several companies plan long term over 10 years and then annually while others include a five year review in between. One company claimed to start with a five year horizon only and made a special case out of significant plant developments.

In many instances, different computer programs are used depending on the time scale, owing to the different level of detail handled. Some companies, however, by flexible program design, claim to use the same programs over all necessary time scales.

Half Year, Quarterly, and Monthly Planning

Still operating basically on a forecast demand, the plans laid on an annual basis are reviewed periodically by all companies. The frequency and the extent of such revisions varies a great deal and ad hoc revisions may well take place at any time if some catastrophe hits.

Not all companies review at the six, three, and one month points, but some do. Mostly the same routines and a similar level of detail are used at each review point, compared with annual planning; however, the amount of time and effort expended depends on the magnitude of any changes found to be necessary.

Some processes, for example, section mills and billet mills, can handle only a very limited range of product sizes at any given point in time. This occurs because each set of rolls is shaped to roll a specific size and changing from one set of rolls to another is a major operation. For such processes, the objective is to group together as many individual order lots as possible so as to enjoy a long production run, lasting say several hours or days. A consequence of this practice is that a particular size and shape may be rolled only once every 6 to 10 weeks, hence an order received in the meanwhile must wait until the next time the mills are set up to handle the dimensions called for.

Another task carried out approximately every quarter is to determine the program of sizes to be rolled (sequence and run duration) over the following three to four months, based on past demand and the sales forecast. Computer models exist to aid this type of production planning. Usual practice is to advise regular customers of the planned timetable, and, where a customer has some flexibility, knowledge of the plan can attract actual orders to the periods wanted.

The Scheduling Phase

A sequence of production planning routines has been described which results in a more and more refined production plan as time goes by and as the actual production period approaches. The plans for each individual process represent the anticipated load of order types and quantities, but it remains to be seen what mix of orders actually arrives. The section covering Order Processing contains a description of the stages through which an order must pass through until it is loaded onto the plant. A list or load is built up for each process and for each production time period. Each process has its own inherent cycle length and this is an important factor in deciding the period lengths. In a given works, the planning and scheduling system must cope with several different time scales.

A blast furnace cannot change very quickly (for example, iron analysis, rate of working) and, indeed, control systems are designed so as to ensure a steady, consistent production. Most companies calculate a monthly production plan for their blast furnaces. Similarly, the coke plant and the sinter plant aim to supply the blast furnace with steady, consistent materials (coke and sinter); these units are planned monthly in harmony with the blast furnace. On the other hand, steel making moves much faster; a typical cycle time per furnace is less than one hour. Most companies have chosen one week or 10 days as the basic steel making production period.

All the other processes, each with a variety of constraints, are also planned over periods that are subdivisions of the calendar month. Since the number of weeks in the month is nonuniform, this causes phasing problems that are usually handled by:

a) ignoring the calendar month at this stage and defining the year as having 13 four-week months;

b) splitting each month into three 10-day periods. This is imprecise because of February and the 31-day months, but, in practice, the odd day causes little trouble;

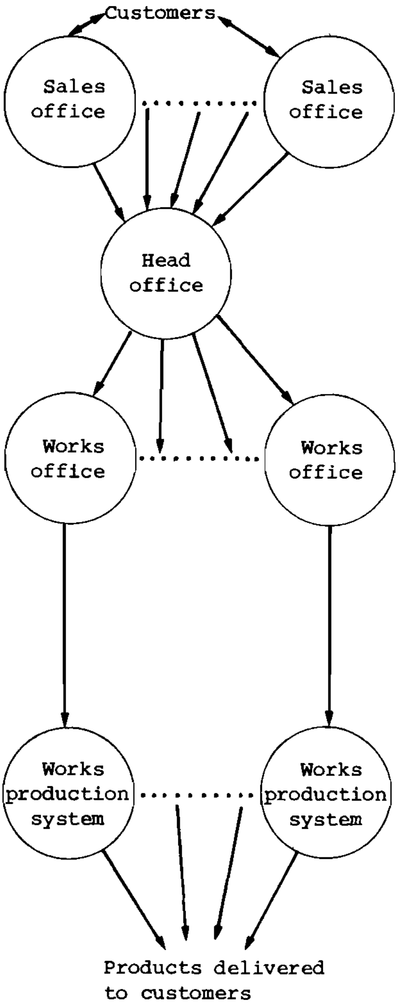
c) splitting each quarter year into three months of four, four, and five weeks duration. This is a common practice but one suspects it caters more to the needs of accountants than production management.

For each process, there comes a point in time when the detailed sequence of items to be produced in a given time scale must be specified. This is scheduling. Dividing the monthly plan into weekly assignments that estimate the sequence of items to be produced during each week constitutes a monthly schedule. Similarly, dividing the weekly plan into assignments for each day composes the weekly schedule, and so on. The more detailed schedules give the sequences of separate operations, considering the times required for their fulfillment.

Order Entry System

Production plans, even quite detailed plans, can be and are determined without any knowledge of firm orders and based purely on estimates of the expected demand. As mentioned already, many longer-term activities, such as building plants and negotiating long-term contracts for raw materials, of necessity must be founded on forecasts.

Eventually orders do begin to arrive and it is necessary to examine each order before accepting it and to determine just how the items are to be produced before priming the work's production processes. This operation is called Order Entry, and it is particularly critical in market oriented countries (see Figure 5).



Basic Functions

Customer/Company negotiations; manual check of orders; coding.

Detailed check of order, basic determination of how ordered items will be produced; confirm delivery date; allocate to works; send acknowledgment to customer.

Calculate processing details; combine orders into lots; allocate to production periods; adjust to balance loadings; prepare detailed process instructions.

Produce products to specification and to committed delivery date.

Figure 5. Order entry.

Sales Offices

Customers normally negotiate directly with a sales office, often located well away from the steelwork sites. If some unusual form of steel is wanted, there may be detailed discussions between the technical experts of both the customer and the steel company to decide precisely what type of steel is best suited to the purpose. Most steel companies take a strong paternal interest to ensure that a customer orders a type of steel that properly suits his needs. Some go as far as to guarantee that the delivered product will fulfill its intended purpose. It follows that, in general, the sales office receives orders for items that are either to standard specifications, repeat orders, or orders for previously discussed new types of product.

The first task of the sales office is to check manually the order for completeness of information and consistency. In many cases the order is transcribed into a standard format with many of the details coded in the process. This stage is largely a manual operation although some mechanical assistance in selecting codes is found in some offices.

Examples exist where a major customer prepares orders in a standard format agreed between customer and steel maker; this both saves time and each order is likely to be more completely and accurately specified. The "ultimate" also exists where the customer transmits his orders via a computer medium, for example, a magnetic tape file. In such a case, the magnetic tape may be physically transported from customer to steel company or, if the distance is too great, it may be transmitted over telegraph lines.

A customer normally wants to know these things: 1) Is my order acceptable? 2) How much will it cost? 3) When can it be delivered? A sales office can usually answer items 1) and 2) without difficulty but 3) can often present problems, especially if the customer is pushing for a very early delivery date.

Practice varies around the world but the most usual solution is for the production planning and scheduling functions to advise the sales offices periodically (daily in some cases) of the standard lead times that can be fulfilled for each product classification. For example, orders for billets may be accepted for delivery in a minimum of three weeks hence, and for sheets in a minimum of six weeks. There is always some absolute minimum time which is dictated by basic processing times, but the practical delivery time will depend on the number of orders currently awaiting processing. It is common practice for a sales office to be authorized to negotiate and agree on delivery dates based on the guidelines already mentioned and without any reference to the detailed production loading or schedules. The only exceptions are for very special steels that may have a dozen or more critical stages of manufacture, some through processes of strictly limited capacity. In these cases, a trial loading is used to calculate a reasonable delivery date.

For some products it is feasible to provide the sales office with a list of unallocated stocks that could be delivered to a customer without delay. Normally, only common steel grades and product sizes are handled this way.

In markets where the sales office has some flexibility in negotiating a price, the list is used to provide details of standard and marginal costs as a basis for profitability calculations. Examples exist where this is taken one further step of sophistication with an indication given to the sales office as to what types of orders to encourage and what to discourage. The classification and ranking of products are based on a comparison of current production loads with the ideal, minimum cost works loading. Such a system is not so crude as to expect the sales office to tell a customer his advance order is not wanted; it simply sets the minimum acceptable price for "wanted" orders.

However the order arrives at the sales office, after the checking already mentioned, it must be sent on to the head office. Naturally, the head office may receive orders from several sales offices or agents and may also deal with some customers direct. Tradition influences current practice.

The order information is passed from sales office to head office in some standard format. In some instances, the details are on paper and sent physically to the head office. Where distance is a problem, a facsimile may be sent over a telegraph wire. However, since most advanced systems today employ computers for production planning and scheduling, the trend is to introduce a new order into the computer system as early as possible. In consequence, many sales (and even agent) offices have a terminal linked by telegraph to the head office computer and this allows the order details to be typed directly into the computer format. In cases where the terminals are fully on-line, order details can be checked immediately for validity and completeness.

Head Office Order Processing

Assuming that the order details are available at the head office in some computer media, the head office activities are virtually fully performed by computer. Again the order details are checked for completeness and sensibility, and the coding carried out at the sales office is validated. There are systems in use that require no further manual operations at the head office except to deal with error, misfits, etc., detected and thrown up during the checking stages.

The first head office task is to build up a basic picture of the processing necessary to produce successfully the ordered item. This involves pulling appropriate details from files containing metallurgical specifications, production routes, etc.

The codes already applied by the sales or head office represent the key to locating the correct details. Thus, a full processing specification begins to be built up.

Once it has been decided *how* an order will be fulfilled the next question is *where*? and *when?* "Where?" implies selecting a works or plant which is capable of producing the ordered item; "when?" implies ensuring that the plant loading situation will allow the items to be produced and delivered to time. The files at the head office will contain details of which plants can make which items and usually some cost information which aids the selection of the most suitable plant (if there is a choice). This selection is a two stage process in most companies. The first stage is an allocation of *forecast* demand to the various plants within the company. A recalculation may take place annually or quarterly and most companies today use some form of economic model to minimize production and transport costs by a suitable allocation of expected demand.

When it comes to allocating a real order, the second stage, the task requires little effort if the order details conform with the expected demand pattern. Trouble does arise, however, if the actual pattern of demand differs from the expected or if production capacity fails to materialize through breakdown or other problems.

Most order entry systems have a model to cope with the situation of finding no available capacity at the "ideal" works. The system attempts to locate alternative suitable capacity that, by definition, will result in more costly (but hopefully still profitable) production. If after attempting to load on several (progressively worse) alternatives, plant capacity still cannot be located, the problem becomes one for manual attention. The alternatives at this point boil down to admitting failure to confirm the requested (and possibly agreed upon) delivery date or to using a higher grade steel which further reduces profitability.

No one cares to admit it, but in really tight corners the company may decide its optimum overall strategy is to delay one customer's order in favor of a more "important" customer's wishes. This type of situation can be handled only by top management, although a computer could be programmed to throw up the hard costs of alternative strategies.

When an order has been successfully allocated to a particular works, it is transmitted, complete with all its detail, to the received orders file of the works level computing system. With many modern systems this transfer is effected via magnetic tape files or by telecommunication lines. In some of the companies visited, the head office compiles the orders destined for each steelworks in the form of a detailed monthly production plan which is transmitted beforehand to the works office. The final action for the head office level is to produce an acknowledgment to be sent to the customer, confirming the details of the order and the agreed delivery date.

Works Office Order Processing

Accepted orders arrive at the selected works office and represent firm commitments. It is the task of the works planning and control system to organize all works productive facilities so as to satisfy these commitments at minimum cost.

The works level computers will first examine the order details and then estimate the technological routes and instructions for their fulfillment. Then, all orders having similar technological instructions and delivery times are combined in lots and compiled in the works orders file. Each file item specifies the amount of steel required, the processes through which the steel must pass, and the numbers and sizes of all intermediate products. In calculating quantities, account is taken of the yields normally experienced in each successive process. By considering the normal processing time and the known basic schedule requirements for each process (for example, the cycle of shapes and sizes planned for the section mill, considering the standard time for changing mill rolls), a processing time table can be drawn up specifying dates within a given time horizon on which the steel should be scheduled onto each process along the selected technological route.

If each component of processing is then added to the load already allocated to each process time period, the order can be said to be loaded onto the plant. In general, the longer the time horizon considered, compared with the cycle time of the production operations, the easier it is to perform the plant loading. Thus, in the simple case, there is enough uncommitted capacity at each process to accommodate all of the orders. Even when this is the case, however, some processes may become unduly loaded with specific product types and some reshuffling should take place in order to balance the plant loadings. This level of readjustment does not normally alter the production date of any specific order item to an extent that jeopardizes completion of the due date.

In cases where there are alternative technological routes, optimization techniques may be applied to allocate the orders (for example, two merchant mills of different sizes may be available to roll the sizes and shapes required by a given order but with different production costs). All has now been done to indicate the load on each process over a scheduling time horizon but not the sequence of items to be processed within that time horizon. That determination is performed at a time prior to the actual production date which is dictated by the length of the processing cycle; this is discussed under "Scheduling".

Before the processing of a new order can be properly called complete, the works level routines compile the detailed processing instructions for every item at every process it will pass through, including transportation moves and sequence changing stock areas. This involves adding to the number, weight, and dimensions of each intermediate product already calculated for the loading process, all processing tolerances, temperatures, processing characteristics (for example, heating cycle coded at the annealing stage), test and quality checks again with limits. All these data are stored on what is usually called the Works Order File.

The order processing procedure, being the main part of the works production scheduling, greatly influences the efficiency of the works operation. It is performed as a mutual task of the order processing operator and the computer through a form of interactive dialogue. Thus, in the simple situation where there is enough capacity and no alternative plant loadings have arisen, the operator's role is simply to approve the decision made by the computer (through some heuristic algorithms programmed in the computer). But in the case where there are alternative loadings to be resolved, the final decision is made by the operator.

In one of the steelworks visited, an order processing system is in use where each order received is compared with the data of previously fulfilled orders. If it is a repeated order, the relevant technical data is taken from the data bank and displayed to the order processing operator. If the operator agrees with this data, the newly received order with its corresponding technological routing and instructions is put into the order file. An entirely new order that does not have a prototype in the data bank is processed in the usual way (with the help of the computer), and, after its fulfillment, all of the technical data is stored in the data bank. In this way, the number of entirely new orders entering the order processing system may be decreased progressively with time.

"State of the Art"

As written, this has been a description of a typical up-to-date planning and scheduling system. A number of examples were seen in which every stage of order processing is performed automatically by computer routines with the exceptions of the initial manual scouting and coding stage and any decision mking required for the resolving of conflicts. This is not to say such systems automatically cope correctly with every eventuality; they do not. They are programmed to search for expected characteristics, and they process the expected correctly, but any incompatible or unrecognized data are rejected. This means the details are printed out for manual attention while being retained on file pending correction.

The combinations of different process specifications are legion, and by no means every combination can be held on file. Only practiced or expected processing combinations are in fact recorded and the normal procedure for some completely new processing combination is to manually specify the details before the first real order is fed in. Everyone spoken to for this survey expressed a healthy dissatisfaction with existing systems. This is not to say that the systems are no improvement over comparable manual systems; they most certainly are on the grounds of speed and accuracy alone.

Speed or response is a critical measure of achievement and some systems have reduced the time from order receipt to formal acknowledgment down to 24 hours. A second measure is the minimum size of customer order that is economically reasonable to manufacture. This minimum may be considerably reduced by an effective order processing system through the combining of similar small orders into lots of adequate size.

The main source of discontent is centered on the algorithms for allocating orders to works for production loading and balancing. No practical and precise optimizing routines are known and so, although "good" answers result, they cannot be called the "best" possible.

Few people expressed satisfaction with the system for calculating and quoting delivery promises although a highly reliable delivery performance against promises is considered generally to be an extremely important objective. It is simple to have very high success rates, on the few orders one would get, by quoting cautiously long lead times. By quoting overly optimistic delivery times the orders may flood in until customers realize that the quotes are unreliable, whereupon business will drop off. The reasoned "optimum" position between these two extremes is not easy to locate and the "correct" answer may change with changing conditions.

Production Scheduling

Every process has inherent constraints and requirements. For example, steel type "p" cannot be made in the same furnace immediately after steel type "r" because type "r" contains a high proportion of phosphorous and type "p" needs a very low concentration. Rolling mills nearly all have sequence constraints and since rolls wear with use, their satisfactory life time dictates cycle lengths. Air heating processes take a minimum time, etc.

The operations level, and this includes services, transport, etc., as well as the basic technological processes, needs to be told what to do and when. A production schedule that contains the necessary identification, the before and after characteristics, and the processing sequence must be produced for each process at a time suitable for the process. In addition, test details must be available.

Although, many computer-performed tasks, for example, accounting, invoicing, process control, are accepted as commonplace in today's modern steelworks, the scheduling process has remained a stronghold of human control. It is an ideal stronghold because, although the main rules and objectives are simple, the caveats, special conditions, etc., result in a seemingly unfathomable set of restrictions.

There are, in fact, many scheduling programs found in steelworks around the world. This is not to say that they are all used on a regular basis or that their results are implemented blindly without manual scrutiny. A steel processing schedule is very critical and production management maintains a constant vigil against anything that might disrupt the smooth, efficient flow of production, or, worse, that may damage the equipment.

A sharp distinction between computer and manual scheduling should not be made, however, since all up-to-date systems include routines that sequence production items as preparation for determining the production schedule. The degree of sophistication involved in this programmed sequencing does vary, however. In many cases, the resulting sequence represents a feasible but not particularly optimal schedule. In all cases, manual schedulers review the computer result and either accept or adjust the generated sequence.

Rescheduling

The system at the operations level implements the schedule, or suitable portions of the schedule, by comparing input identification codes and other data with those indicated on the schedule. Many sources of divergence from the planned schedule may occur owing to 1) nonavailability of an expected item, 2) process breakdowns or restrictions, 3) malprocessing. The operations level will either detect such variances itself or be informed via manual input. However the variance arises, a situation immediately exists in which implementation has failed in the planned form and some remedial action must be taken. The failures range from simple sequence errors that, provided identity can be maintained, can cause anything from little real trouble through to full process breakdowns.

For malprocessed items, a full spectrum of attitudes was found ranging from:

a) use of a complex on-line search routine to match the "unwanted" item against the existing list of orders. Thus, if a suitable order is located, the marriage is made and processing continues, perhaps with some changes in detail; a remake order is then raised to cover the "disappointed" order; to

b) the complete removal of the offending item to some storage area where it rests until a manual decision is taken about its future. A remake order is also raised.

Various approaches exist that fit somewhere between these two extremes.

In cases where the problems are much bigger, for example, a steel making furnace must be shut down, the repercussions are more significant, and the consequences more far reaching. The basic philosophy of the planning and scheduling system explains the way out.

Plans are originally made in the expectation that production will proceed with a normal degree of success. That is to say, for example, that 100 tons of steel will result in, say, 85 tons of sound hot rolled coil. The daily loads on each process reflect these plans but detailed scheduling is not finalized until 1) the material which is physically ready to be taken through the next process is known, and 2) the state, condition, and capabilities of the process have been assessed.

The scheduling stage accepts the material and equipment as it is and attempts to derive an optimal production sequence within the existing constraints. Thus, although material and process may not be exactly as planned, the best that can be achieved under the experienced constraints will be determined.

Operational Level of the Integrated Control System

General Considerations

As described earlier, there is an operational level of control between the production scheduling level and the process level that translates the schedule into control actions initiating the various manufacturing operations. This ensures that the quality and yield requirements for prescheduled orders are met.

The operational level of control is sometimes called the coordinational level, or production control. Since the function of this level includes organization of the processes, and its goal is to react operationally to all deviations from the schedule, the term operational level seems appropriate.

A steelworks usually has three main production stages: iron making, steel making, and steel rolling. Iron is produced by blast furnaces; steel is made in open hearth furnaces, oxygen converters or electric arc furnaces; steel rolling is carried out on various mills and is divided into two parts, primary and secondary rolling.

Figure 6 represents a typical flow of processed material through these stages with the steel making facilities represented by oxygen converters, and the primary rolling by a universal slabbing mill. Ore is blended and delivered to the sinter plant (in some cases through an ore enriching plant). Coal, after

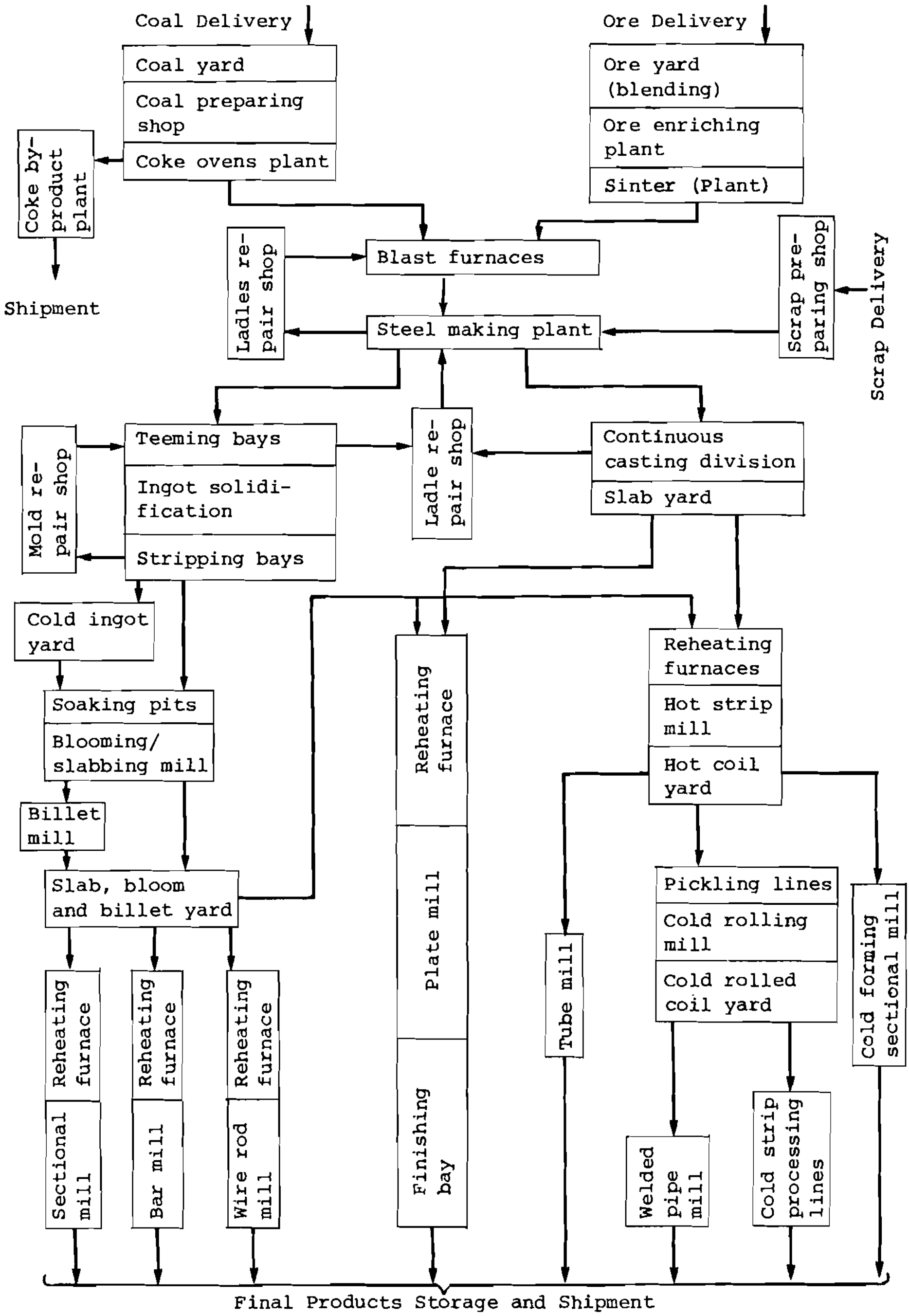


Figure 6. Material flow diagram for the steelworks.

being crushed and blended in the coal-preparation shop, is delivered to the coke oven plant where the coke is produced. Coke gas, a by-product of the plant, is refined and used as fuel for the different reheating units. Benzol, coke tar, and other chemicals obtained as by-products are shipped to customers.

A steelworks usually has several blast furnaces. The main components of the blast furnace charge are sinter and coke delivered from the sinter and coke plants, respectively. The hot iron from the furnaces is delivered in ladles to the steel making plant. In a modern steelworks, these ladles are of the Torpedo type, which means that mixers are not required.

Several types of technology are used to produce steel from crude iron; the most advanced is the oxygen converter process which permits large amounts of scrap to be used. The large-sized scrap is crushed in the scrap-preparation shop and delivered to the scrap yard in a form suitable for direct use in the converters. After scrap has been charged, the hot metal is poured from a ladle into the converter.

Steel produced at the steel making shop and tapped into steel ladles can be sent on to continuous casting machines or poured into ingot molds at the teeming bays, depending on the technological route established by the production loading procedure. The continuous casting machine can produce slabs and billets of various sizes; for simplicity, Figure 6 shows only the production of slabs.

After the ingots have solidified in the molds (the time required depends on the grade of steel), they are stripped at the stripping bays and then sent to the soaking pits. When no pits are available for charging the new ingots, or when the steel grade does not match the specifications of the plan, the ingots are sent to the cold ingot stockyard. They are normally charged into the soaking pits at some later time when there is a delay in delivery of new ingots from the stripping bays.

The empty ingot molds are repaired and stored in the mold repair shop. When needed, they are delivered on a special mold train to the teeming bays. After teeming, empty steel ladles are sent to the repair shop until called for by the steel making plant.

The primary rolling stage shown in Figure 6 is performed by a universal slabbing mill that can roll ingots into slabs or blooms. If the mill is rolling blooms, these may be sent directly to the billet mill, the section mill, or the bloom storage yard. Billets from the billet mill (or the billet storage yard) may go to one of several finishing mills, such as the bar mill or the wire-rod mill.

Flat rolling is represented in Figure 6 by the heavy plate mill and the continuous hot strip mill; both can roll slabs produced by the continuous casting or by the slabbing mill. Since, the heavy plate mill will often require slabs of different sizes, these are rolled by the slabbing mill which is capable of easily changing slab size. Both mills have several slab reheating furnaces; in addition, the plant mill has a well developed finishing bay consisting of inspection and shearing lines, as well as packing and shipping departments. The hot strip mill produces steel strip in the form of coils and there is a coil yard at the end of the production line where the hot coils are kept while cooling.

Usually, most of the hot rolled coils are used as semifinished products for cold rolling. Pickling lines on the entry side of the cold rolling shop remove the scale from the surface of the hot rolled strip by chemical treatment. The rolling facilities of the shop generally consist of tandem-type rolling mills, having four to six stands, one or two temper mills, and several single-stand reversing mills for the production of narrow-gauge strip in small quantities. There are also strip heat treatment furnaces of batch or continuous type, shearing lines, and coating, tinning and galvanizing lines. All these facilities are combined in a so-called cold strip processing department.

Often, steelworks with hot and cold rolling strip mills have tube and pipe mills of different types that use semifinished products in the form of hot or cold rolled strip. In some cases, there is a cold forming sectional mill producing different sections from the hot rolled strip received from the slitting lines. Each mill has a roll repair shop (not shown in the figure), where the worn rolls are ground and polished.

As can be seen from Figure 6, the technological processing routes of the steelworks increase in number toward the dispatch end of the works, thus enlarging the information flow and increasing the complexity of the coordination control problem. The technological route starts to branch at the steel making plant, where the operation is of a cycling type and each cycle can correspond to different requirements. Each converter heat can be of different steel grade and assigned to a different technological processing route according to the order requirements. More technological branches appear at the steel rolling stage according to the different sizes and shapes of the rolled metal. The technological instructions required are precalculated and stored in a data bank from which the operational control system draws information in the form of local control system assignments.

The following descriptions of operational control systems do not relate to any particular steelworks; they are prototypes embodying the more advanced parts of various systems. The main aim of the descriptions is to outline the characteristics and capabilities of the operational systems for different stages of the production process.

Iron Making

The iron making division includes the raw material yards, coke and sinter plants, and blast furnaces. A specific feature of this division is that the operations are continuous and the specifications of its products are generally independent of the orders for final steel products. Thus, the coke plant always produces the same coke, the sinter plant the same sinter, and the blast furnaces the same iron. Such bulk type production processes, which operate to a constant technology, are simpler to control since the objective is to stabilize the process and to keep them running continuously on the same technology.

The control of the ore-blending operation consists of programmed switching of the ore conveyer sections and excavating units in accordance with decisions made by the ore yard operator. The operator has all the information concerning the ores stocked in different piles and the transportation operations that are carried out by the conveyers together with the excavating units. Initial information about newly delivered ore is fed manually into the yard's operational control system and all ore movements in the yard are recorded automatically by the weighing sections of the conveyers. On request, the system gives the total amount of ore delivered to the yard and the present ore stock.

The operational control system for a sinter plant has mainly monitoring functions, which assist the sinter plant operator to detect in advance any deviations of the process caused by material shortages or by poor estimates of technological conditions. The system checks the amounts of material in the bunkers, and on the basis of periodic chemical analyses of these materials, calculates the composition of the sinter.

The cyclic operation of the coke ovens includes charging the ovens from the top with raw coal, firing them, and discharging the hot coke from the ovens by a special machine. The operation of the discharging machine should be coordinated with the door extractor crane operation that controls the position of these mechanisms. Thus, one of the functions of the coke oven operational control system is the tracking of the discharging machines, door extractor cranes, and coke transfer cars. The hot coke discharged into a coke transfer car is taken to the coke quenching tower where program-controlled coke quenching operations take place.

There is a strict sequence in carrying out these operations for each oven; this sequence is controlled by the operational control system which monitors the oven's cycling operations and maintains their proper phasing to satisfy limitations of the discharging and coke quenching equipment.

The blast furnace operational control system, usually considered part of the furnace process control system, consists of several local systems, for example the burden charging system comprising a fully automated, programmed controlled weighing ore car (or conveyers), skip hoist, large and small bells, distributor, and coke weighing gridle. The operational system may also include the hot blast stove programmed controller that alternates the stoves between heating and cooling phases to obtain hot blast for the furnace. The data-logging system, which can also be considered part of the operational system, calculates the burden.

Steel Making

Figure 7 shows the main material flows through the oxygen converter plant. On the entry side of the plant there are the flows of hot metal, scrap, additions, and oxygen. Hot metal is delivered in ladles from the blast furnaces and weighed before being poured into the converter vessel. Scrap is delivered from the scrap yard in charging baskets and is also weighed. Additions are stocked in hoppers and delivered by conveyer to the converter weighing bunkers. Oxygen is produced by the oxygen-making shop.

On the exit side of the plant, the figure shows the flow of steel in ladles, which are delivered to the continuous casting department, and the flow of the ingots in molds, which are delivered to the stripping bay. Material movements inside the plant are by ladle transfer cars that deliver the ladles to points from which they can be taken by overhead cranes: slag cranes for slag ladles, teeming cranes for steel ladles operating at the teeming bays, and teeming cranes in the continuous casting department.

To organize and control the operation of the steel making shop, the position of all the transport units must be monitored, the weight of the material flow measured, and the levels of the material in the hoppers checked. To control the converter process, the temperature must be measured and hot metal and waste gases analyzed and measured.

The organization of the production process is a function of the operational control. This control should check the sequence of the individual operations, such as delivery and withdrawal of the ladles for steel and slag to and from the converter, delivery and withdrawal of hot iron ladles, charging hot metal and scrap into the converter, lifting and inclination of the converter vessel, and so on. The operating cycle for a two-converter plant is shown in Figure 8. Because of the limitations of the transportation and teeming facilities, the operating cycles of the two converters must be out of phase by ninety degrees. Ensuring this displacement is another function of the operational control system.

Figure 9 shows the main functions of the operational control system for the steel making plant. As previously mentioned, the goal of this system is to combine the production planning and

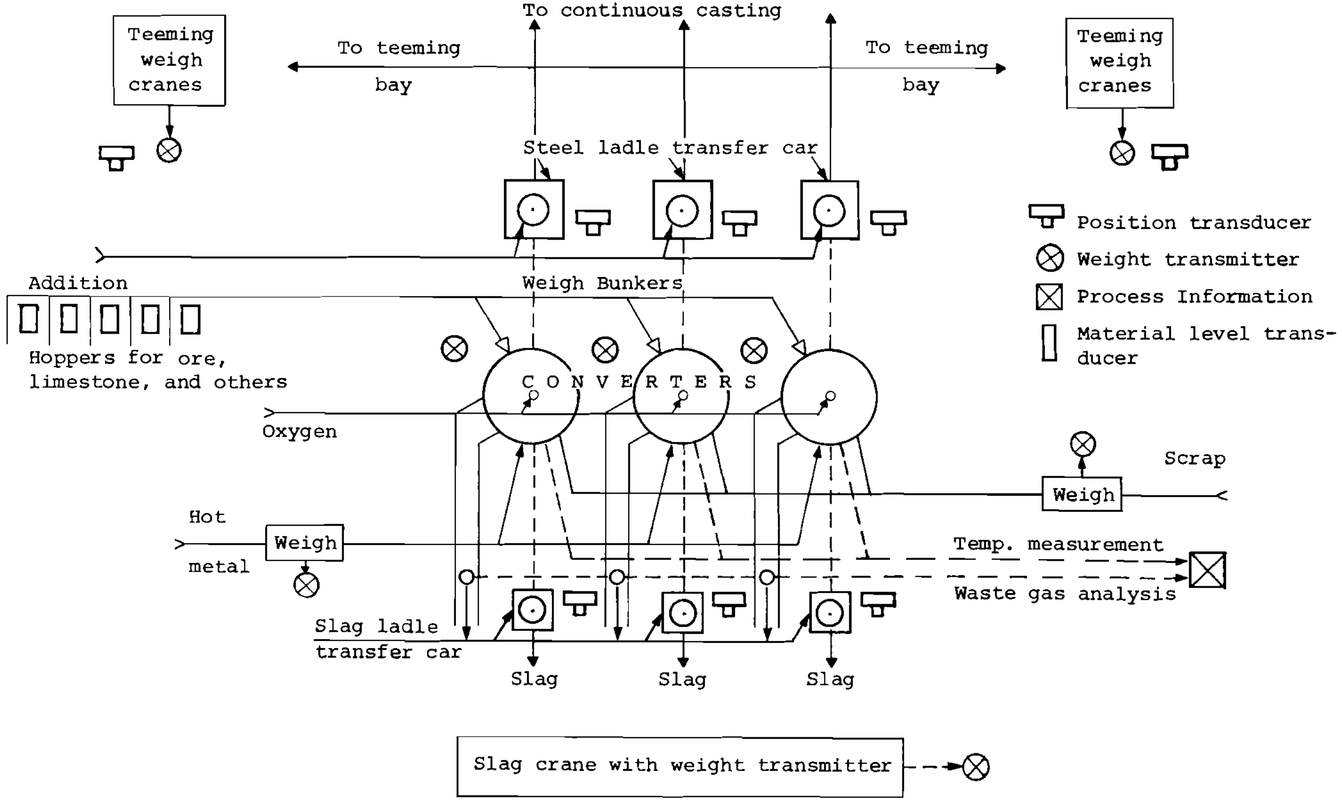


Figure 7. Diagram of the material flow through BOF plant location of transducers and point of measurement.

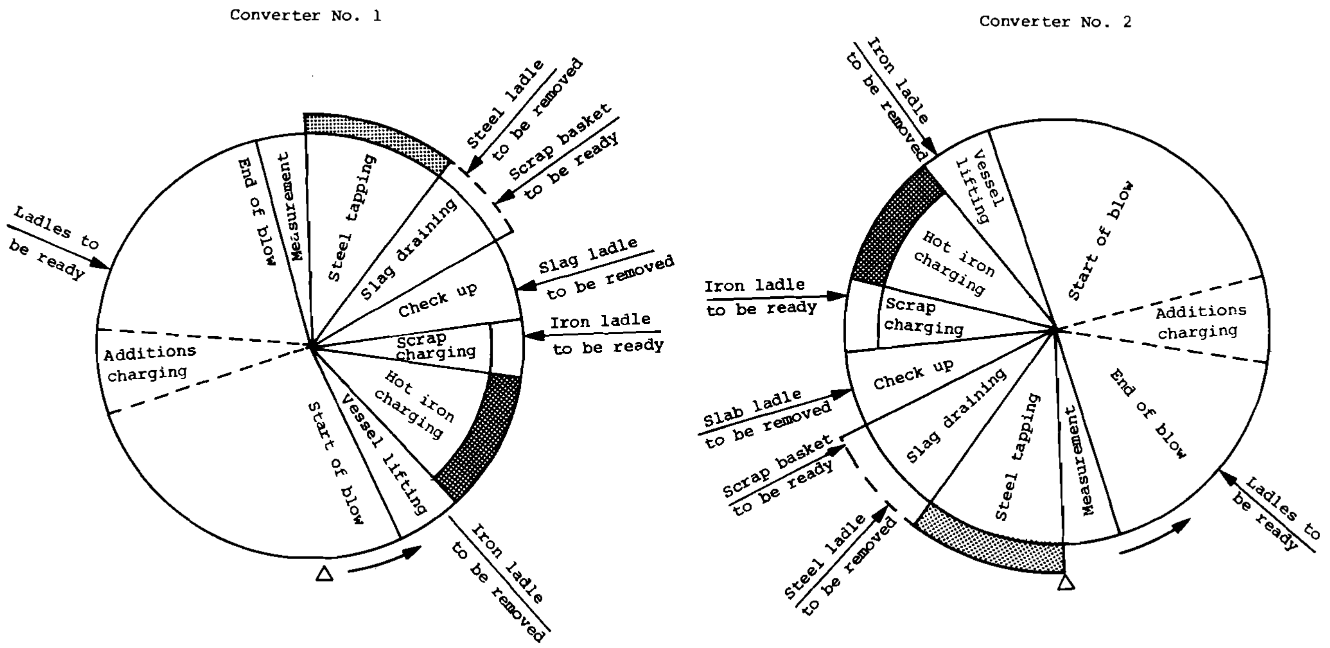


Figure 8. Diagram showing the operation cycles (displaced by 90⁰) of two converters.

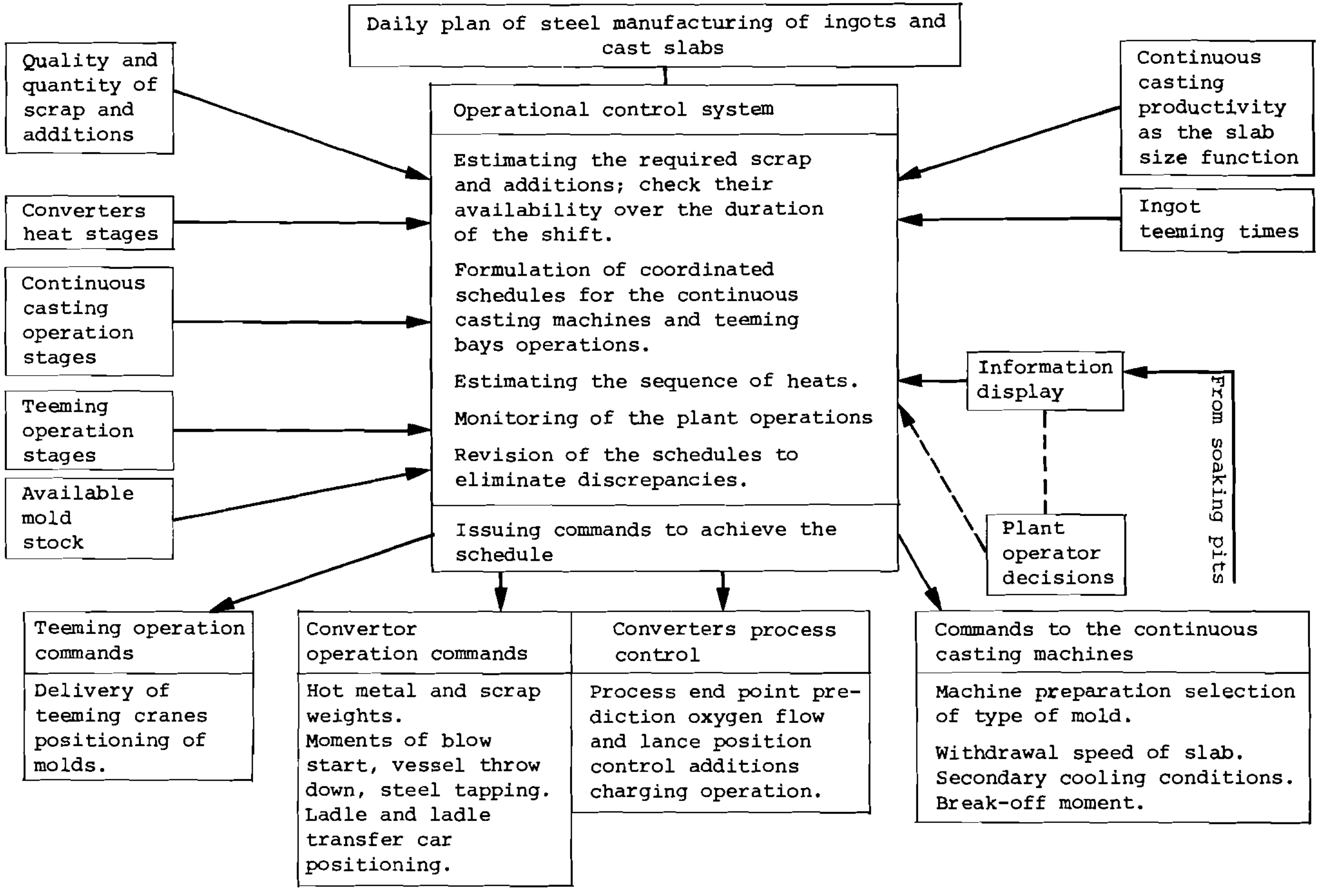


Figure 9. Operational control of steel making department.

scheduling system with the local process control systems. Thus, the assignment for the operational control of the steel making shop is received from the production planning system in the form of a daily plan for steel ingots and for slabs cast in given sizes and grades. The plan gives all the necessary information concerning the required amount of scrap, hot metal, additions, steel and slag ladles, molds, and so on. The calculated figures are compared with the information that each shift receives from the scrap yard, ladle and mold repair shops, and the shop floor; the operational control system issues requests for scrap to be delivered to the scrap yard, ladles and molds to the repair shops, etc.

The daily steel making plan does not indicate the sequence of heats for different steel grades to be manufactured by the converters; it provides only the number of heats of each grade to be sent to the continuous casting division and to the teeming bays, with indications of the type of ingots and the slab sizes to be produced. Because the grade of steel produced by the converter often fails to meet specifications, the detailed schedule is not prepared beforehand by the planning level of the system; rather, the steel making plant assignment is given in the form of a shift or daily plan. The scheduling is performed by the operational control system in the light of current events. It includes preparation of schedules for the teeming bays and the continuous casting machine operations.

The scheduling of teeming-bay operations should minimize the number of heats sent to the cold ingot stockyard. In other words, this schedule should maintain the condition of the soaking pits such that there are always pits available for charging new ingots arriving from the stripping bays. To calculate such a schedule, the duration of the teeming operations and the track time should be considered, as well as the heating time for ingots in the soaking pits, and the rolling cycle time.

Since there are always some heats that fail to meet the specifications and, therefore, must be repeated, the planning system anticipates an average number of such heats and provides for substitutes by charging the soaking pits with cold ingots available from the cold yards. Thus, the teeming bay schedule must consider any delay in the ingots' ready time owing to cold charging of the soaking pit. This reduces the productivity of the pits considerably since the heating time of cold ingots is much greater than that of hot ingots.

The schedule of continuous casting machine operations should minimize the number of interruptions of the machines since such interruptions require extra operations that lead to an increased average cost of slab production. When compiling the coordinated schedules for teeming and continuous casting operations, it is necessary to consider the fact that the cost of idle time on the blooming mill is higher than on the continuous casting machine, and thus continuation of blooming mill operations is of higher priority. Both schedules should ensure that there are no delays in the converters' heating cycles. To achieve this, the withdrawal speed of the cast slabs is varied within permissible limits.

After the coordinated schedules of the teeming bays and continuous casting operation have been determined, the sequence of converter heats of different steel grades is established. In case of deviations from the estimated schedule, the schedule should be revised. It is obvious that the sooner the discrepancy is revealed, the fewer losses the plant will have. Continuous monitoring of the converters minimizes the delay in detecting errors. As mentioned earlier, this monitoring includes control of the transfer cars and overhead crane positions, and the readiness of ladles, mold trains, and so on. Information about the deviations from the schedule is displayed to the plant operator who decides what action should be taken or how to reschedule the plant operations.

The monitoring of operations is closely connected with the issuing of commands for fulfilling the estimated schedule, thus reducing the probability of divergence. These commands are divided into three groups: converter operation, teeming operation, and continuous casting operation.

The operational control system issues information about the grade of steel to be produced by the converter, and the local process control system calculates the converter charge and the oxygen required. The results of this calculation are sent back to the operational system which determines the set points for the local weighing systems for scrap and hot metal. Static and dynamic models of the process are used to predict the process end point and to estimate the oxygen flow, oxygen lance position, and weight and timing of each charge component. Commands sent to the teeming bay identify the number and type of molds to be delivered; they also include commands to the crane operator specifying the teeming bays to which the ladles of hot metal are to be delivered.

The operational control system sends instructions to the continuous casting division to prepare a given machine for operation, to install a specified mold size, and to establish the required cooling conditions and slab withdrawal speed. The system also establishes the moment when the machine must be prepared for a new operation.

Primary Rolling

The teemed ingots solidify in the molds by natural cooling. For this operation, the mold train is brought to the cooling area where it remains for a time depending on the type of mold and the steel grade. Because the cooling time can vary considerably, the sequence of heats leaving the teeming bay may not be the same as the sequence of heats ready for ingot stripping.

The operational control system for primary rolling shown in Figure 10 modifies the sequence of heats to be delivered to the stripping bays and monitors the movement and position of the ingot trains located in the cooling area. The system issues commands for the delivery of ingot trains to the stripping bays, including commands for ingot stripping. The expected sequence of heats leaving the stripping bays is determined in advance, and the predicted time at which an ingot is ready for charging is compared with the predicted situation at the soaking pits (the next operation in the system). This comparison allows an advance estimate of when cold ingots from the yard can be charged in the pits and which heats should be sent to the cold ingot stockyard. If the heat is not sent to the stockyard, the thermal conditions of the ingots are estimated, based on the time between the teeming and stripping operations, the type of molds, and the grade of steel. In accordance with the order requirements, the rolling pass schedule and the rolling cycle time are estimated. These data permit calculation of the required discharge times of ingots from the pits.

Monitoring the condition of the ingots in the different pits identifies which pits are suitable for new ingot charging and establishes the ingot charging operation sequence. After a pit is charged, the computer, having information on the thermal conditions of the charged ingots and the specific characteristics of the pit, predicts the time required for heating (including soaking) the ingots. The predicted ready time for newly charged ingots is compared with that of ingots in other pits; any coincidence of ready times is avoided by slowing down or speeding up the heating in the pits as necessary, that is, the ingot ready sequence may be modified by controlling the heating rates.

Thus, the preliminary schedule of teeming operations compiled in advance and based on the standard data for cooling, stripping, heating, and rolling operations is revised in accordance with actual events. These revisions require knowledge not only of the current situation, but also of anticipated changes in the future. To determine the revised schedule, all the available information is displayed to the soaking pit operator who makes the final decision. He then transmits the details of the revision to the planning system which revises the daily production plan at the completion of each shift, thereby compiling an updated assignment for the next shift. The pit discharging operations are carried out, according to the estimated schedule, by the operational control system which issues appropriate commands to the crab crane operators and to the local system of ingot-buggy position control.

The rolling of each ingot is performed automatically by the local control systems for screw downs, rolling tables and main drive. The operational system (see Figure 11) sends commands to the local systems, as the rolling process progresses, in accordance with the precalculated distribution of the reduction between passes. Only in cases where the rolling load exceeds the

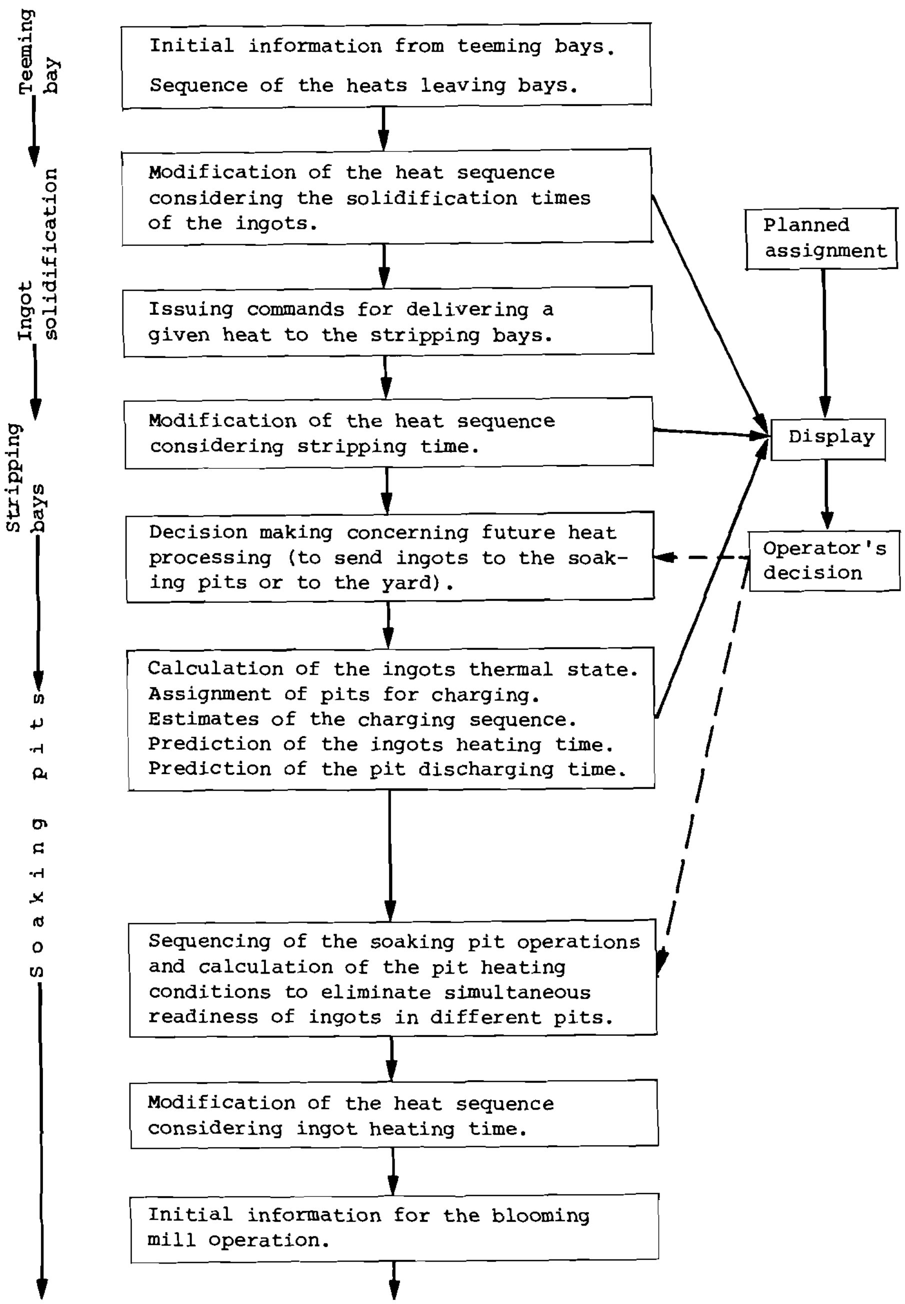


Figure 10. Operational control of the steel making: primary rolling region.

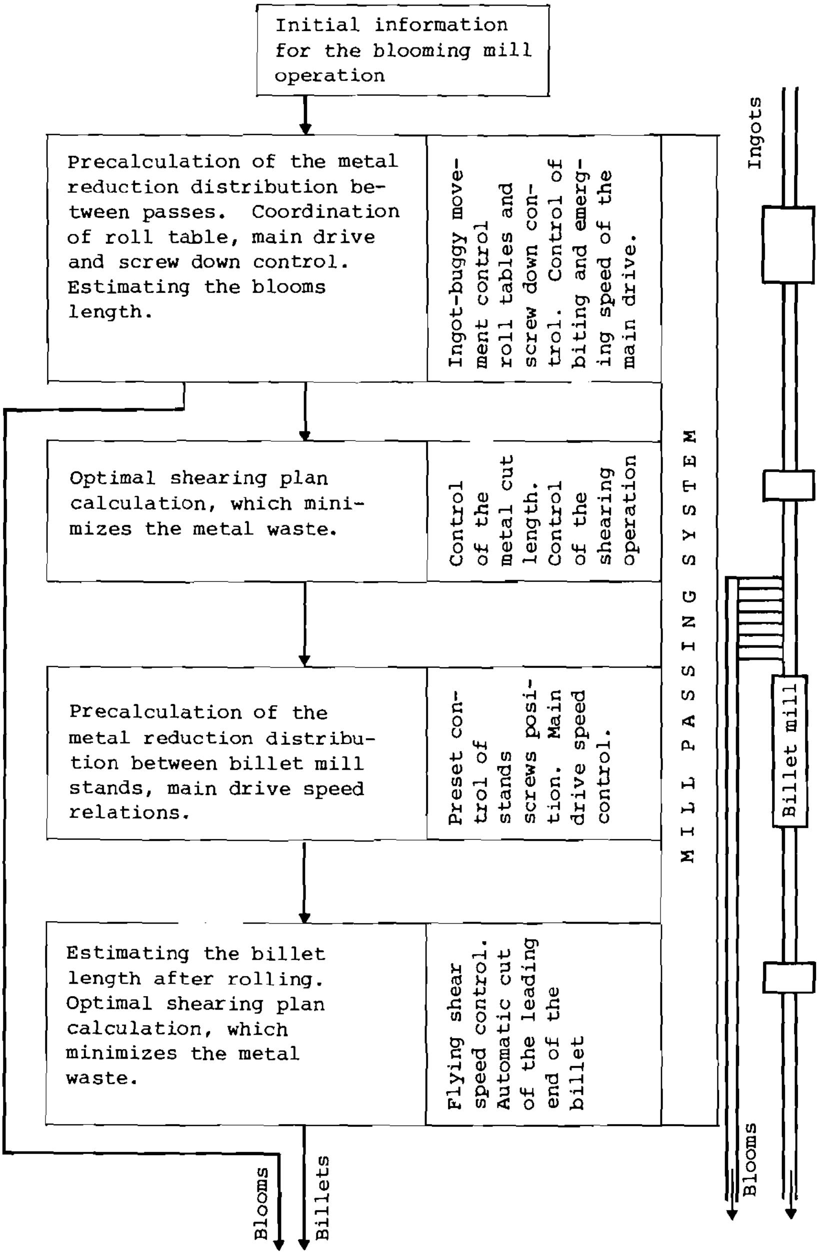


Figure 11. Operational control of primary rolling.

permissible level is on-line recalculation of the reduction distribution necessary. In some cases, instead of on-line calculations, the system has two precalculated reduction distributions corresponding to normal and overload rolling conditions. If the rolling forces are too high, the system switches the reduction schedule to one which calls for more (and hence lighter) passes.

During or after the last pass, the length of the rolled metal is determined and an optimal shearing plan is calculated. The lengths of the metal cuts are given, to within the permissible tolerance, as instructions to the local control system for the shear and the shear rolling tables. If the order to which the ingot is assigned requires blooms, the mill passing system issues commands to deliver these to the yard. When an order requires billets, the mill passing system directs blooms to the billet mill.

The setting of the billet mill is changed by the operational control system after the last billet of a given size is rolled and a new size of billet is to be rolled. This system also gives the assignment to the local flying shears control system, which measures the total length of metal rolled from one bloom and calculates the optimal shearing plan. All the blooms and billets are automatically marked before entering the yard, and the marking is controlled by commands from the operational control system. In addition to monitoring, sequencing and issuing commands, the operational control system performs data logging and accounting functions; this information is sent to the upper levels of the system.

Slab Yard

The semifinished and finished products of the rolling mill are stored in the stockyards until they are required for the next processing stage or for shipment. Because of the batch type production, the amount of metal stored in the yards can be considerable; to prevent subsequent processing delays, it is essential to have complete information on the location and identity of each item stored.

One of the most common failures in yard operation is the "loss" of slabs owing to incorrect recording of their location in the yard. This is generally caused by the lack of accurate feedback from the crane operation in transporting slabs to and from the yard. To eliminate the possibility of such failures, the slab yard operational control system shown in Figure 12 includes devices for controlling the crane operation and its position.

Only two operations are necessary for control of the crane operation: taking a slab off the yard floor and discharging a slab onto the floor. To obtain confirmation of a correct operation, a logic device can be used that checks the position of the crane

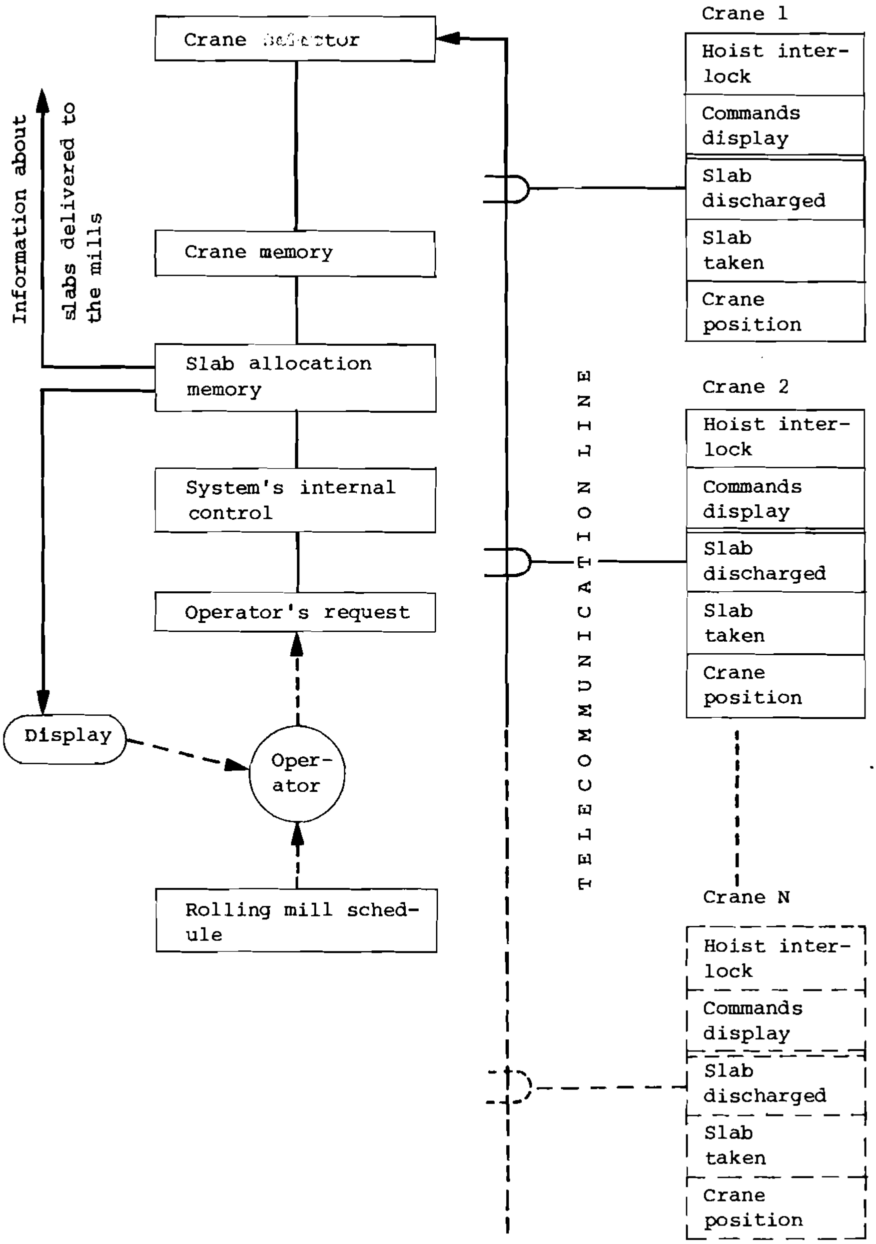


Figure 12. Operational control of slab yard.

hoist and the load on the hook. By fixing the crane position at the moment that the signal of the slab discharging operation is obtained, the exact location where the slab is discharged is determined. The location at which a slab is taken off the floor is determined in the same way. Thus, the computer has information about the location of each slab. At the request of the slab yard dispatcher, the information system presents the required information on a display. For instance, the dispatcher can ask where the slabs of some particular order are located, or where all slabs of some grade of steel of a given size are located.

The dispatcher also has the schedules for the rolling mill operations in the form of a time schedule for slabs to be delivered to the mills. On the basis of this information, he decides what assignments should be given to the cranes. According to these assignments, the system transmits commands by a telecommunication line to the cranes where they are displayed on the crane operator's screen.

To achieve a fully automated yard for rolled metal, the yard can be equipped with rows of shelves for stocking metal. Stacker cranes run between the rows and fulfill the transportation and loading tasks according to commands received from the yard's operations control system. This system has all the information regarding where metal is stored on the shelves and, on request by the yard dispatcher, issues commands to the crane controls so that any required item is retrieved from its storage shelf and delivered either to the shipping department or to the finishing mill entry roll-table, all automatically.

Heavy Plate Mill

To reduce metal waste in the plate shearing operation, the slab sizes are calculated during the order processing stage according to the specifications of the order or group of orders. Thus, each slab delivered to the heavy plate reheating furnace has a definite order assignment, and no alteration of this assignment is normally permitted since this may cause considerable metal losses in shearing.

The heavy plate mill operation requires strict adherence to all the technological instructions selected in advance. Alterations are allowed only during rolling, in considering the actual equipment behavior. For example, the heating program of the furnace should reduce the fuel consumption without affecting the slab's thermal condition; the rolling process operations should ensure that the required plate temperature and dimensions are achieved while minimizing the rolling time cycle (see Figure 13).

For correct operation of the system, it is essential to identify each slab delivered from the slab yard. This information is supplied by the slab yard operational control system described above. A request to the data bank then provides the technological instructions for processing the slab.

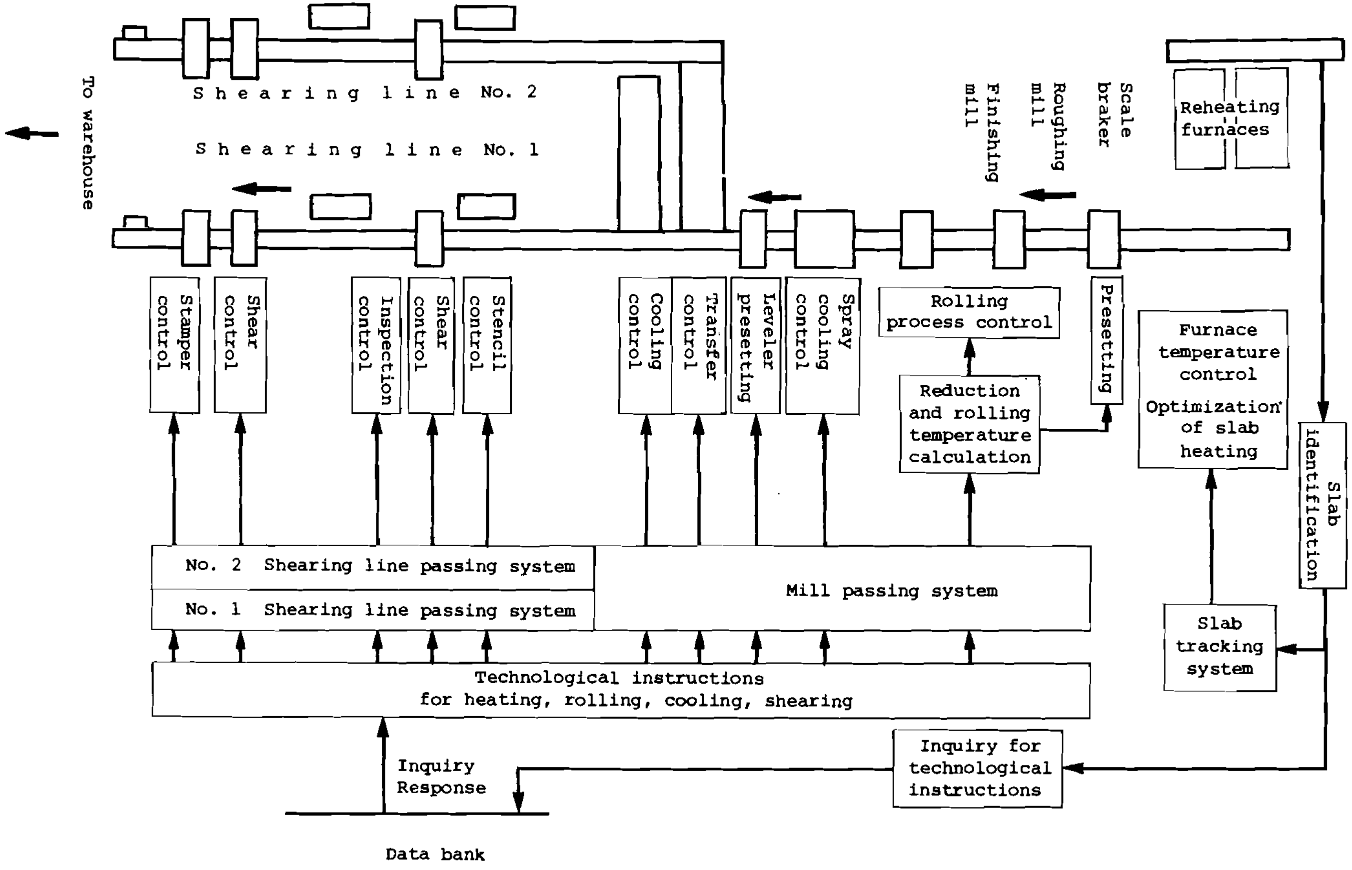


Figure 13. Operational control system for heavy plate production process.

The slab tracking system in the furnace provides information on the location of slabs in the furnace, which may be used in the optimal slab heating program calculations. After the slab leaves the furnace, its movement through the rolling mill line is tracked by the mill passing system and the shearing line passing system; these operate by means of signals received from transducers located along the lines. The operational control system translates the technological instructions into assignments to the local control systems. In addition to these functions, the operational system performs data logging and accounting functions, sending the results to the upper level control system.

Hot Strip Mill

The daily plan for the hot strip mill is prepared on the basis of the weekly or monthly plan, and, during its preparation, limitations on the thickness and width of the strip owing to roll wear are taken into account. Wear of the backup rolls spoils the shape of wide strip; hence the strip width should be progressively decreased during the period between backup roll replacements. Wear of the working rolls spoils the shape of thin strip and thus necessitates increasing the strip thickness during the period between working roll changes. The backup rolls are replaced after seven to ten days' operation; the working rolls may be replaced up to twice per shift. Considering these limitations, the daily plan is made up of orders having items of almost the same width but a broad range of thicknesses.

The sequence is determined in such a way that, after each working roll replacement, the rolling should be started again from the widest strip of the smallest thickness and completed with the thickest strip of smallest width. To satisfy these requirements, small order items should be combined and large order items split. These procedures give rise to an optimal (for a given set of orders) batch of slabs to be rolled in a sequence of increasing thickness, thus ensuring that the maximum length of strip is rolled up to the next working roll change. The fulfillment of this criterion reduces the number of roll changes, thus increasing mill productivity and reducing production costs (changing rolls is expensive). However, as the strip thickness increases the rolling time decreases and the furnace is required to increase its output. This raises the possibility that mill production may be limited by furnace capacity.

Reheat furnace capacity depends on the required slab temperature; that is, the lower the temperature, the higher the capacity. The lower limit on slab temperature is determined by the mill stand load, and in practice can be used only in the rolling of thick strip which requires less metal reduction. A decrease in slab temperature also results in an increase in rolling speed in order that the final strip temperature be within specified limits. Thus, by proper selection of slab temperature as a function of strip thickness, higher production rates on the hot strip mill can be obtained.

To achieve different slab temperatures in the continuous furnace, it is necessary to charge slabs to the furnace in batches, with each batch heated to a slightly different temperature. Thus, if different slab temperatures are specified, this also affects the slab rolling sequence.

Depending on the mill condition, there is always a possibility that some of the slabs included in the prepared sequence will not be rolled when expected so that their rolling must be transferred to another period. Before each roll change, a revised version of the sequence should therefore be determined. This calculation is done by means of a model that gives the relationship between roll wear and length of strip rolled (for different steel grades and strip dimensions).

The slabs are to be delivered from the slab yard to the charging section of the mill according to the previously determined slab rolling sequence. The operational control system for the hot strip mill (see Figure 14) issues requests to the slab yard operational control system in the form of a slab delivery schedule. The operational control system, anticipating the slab discharging sequence, determines the order in which each new batch of slabs is to be charged into the different furnaces. The system also tracks slabs through the furnaces and sends information on their positions to the furnace heating optimization system which, according to this information, establishes the set points for the temperature controllers.

After a slab has been discharged from the furnace, its movement through the mill line is tracked by the mill passing system. The signals generated by this system (as the metal passes each stand and points of control between the stands) are used as commands for the local control system, for example, stand screwdown preset control, mill drive speed control, interstand strip tension control, stand gauge control, finishing rolling temperature control, coiling temperature control, and so on. The set points of these local control systems are determined according to the rolling program. The results can be calculated in advance and stored in the operational control system memory, or they can be calculated just before each new slab is rolled. In either case, the results of the calculation may be revised by an adaptation procedure during the rolling of the slab.

By continuously monitoring the performance of the rolling process, the operational control system estimates the quantitative and qualitative results of the mill operation, providing data for each order and each coil; similarly, plant operation data are recorded for each shift, day, and so on.

Coils are taken from the coilers by conveyers and delivered to the hot strip mill coil yard where they are kept for several

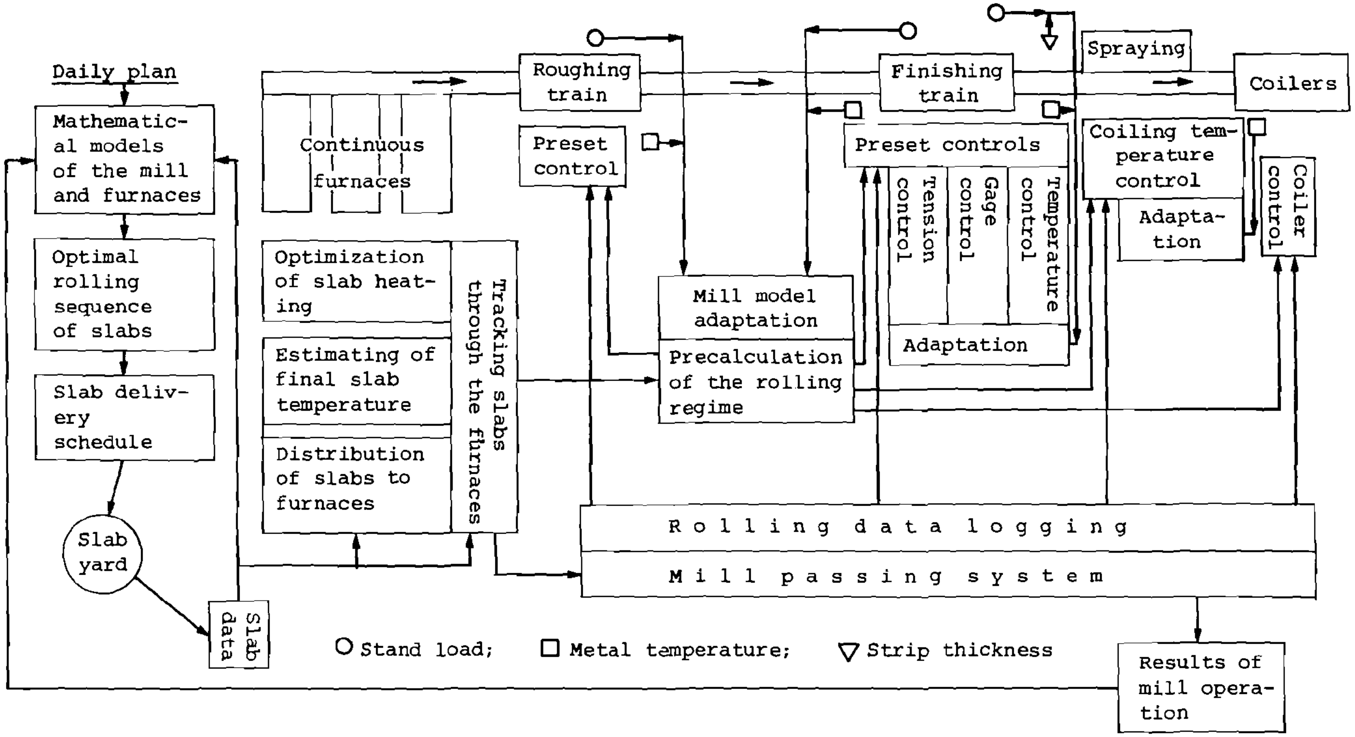


Figure 14. Diagram of a hot strip mill operational control system.

days for cooling. This yard is capable of stocking several hundred coils and has a special information system similar to that described above for the slab yard. Coils in this yard are transported partly by overhead cranes and partly by electric cars.

Cold Rolling Department

After cooling, the hot-rolled coils pass through the continuous pickling lines where scale is removed from the strip surface by chemical treatment. Strip loop accumulators are used at both the start and finish of the line, which allows operators to weld or sew together strips from two different coils without stopping the movement of strip through the baths, and to coil the different strips separately after pickling.

The operational control system tracks the movement of the coils from the coil yard to the entry side of the pickling line and the movement of each strip through the line up to the discharge of the coil from the exit side. By tracking the strip movement, the system determines when to weld the ends of two coils or, on the exit side, when to stop coiling, cut the strip, and start new coiling. Since there is usually more than one pickling line, the system directs the coils delivered from the yard to the appropriate line, considering the pickling processing time.

After pickling, the coils are transported to the cold rolling mill. The productivity of the pickling line increases with strip thickness (since the surface area is less for a given weight coil). Also, the productivity of the rolling mill decreases with decreasing final strip gauge. Since it is not always possible to have equal productivity of the rolling mill and the pickling lines, there is usually an intermediate coil storage area between them. The daily plan is based on equal loading of both operations; however, to prevent accumulations or shortages of pickled coils during the shift, it is necessary to compose coordinated sequences of the pickling line and rolling mill operations. Thus, one of the functions of the operational control system (see Figure 15) is to estimate these two sequences so as to minimize any mill idle time caused by a lack of pickled coils.

The calculated strip rolling sequence allows pre-estimating the rolling practice for each particular coil. Thus, after completing the rolling of one coil, all the data for mill presetting for the new coil are available. This is achieved by means of the mill mathematical model and can be considered as a function of the local mill preset control system (as shown in Figure 15). Data logging during the rolling operation records information on rolling mill behavior which is used for adaptation of the mathematical model of the mill.

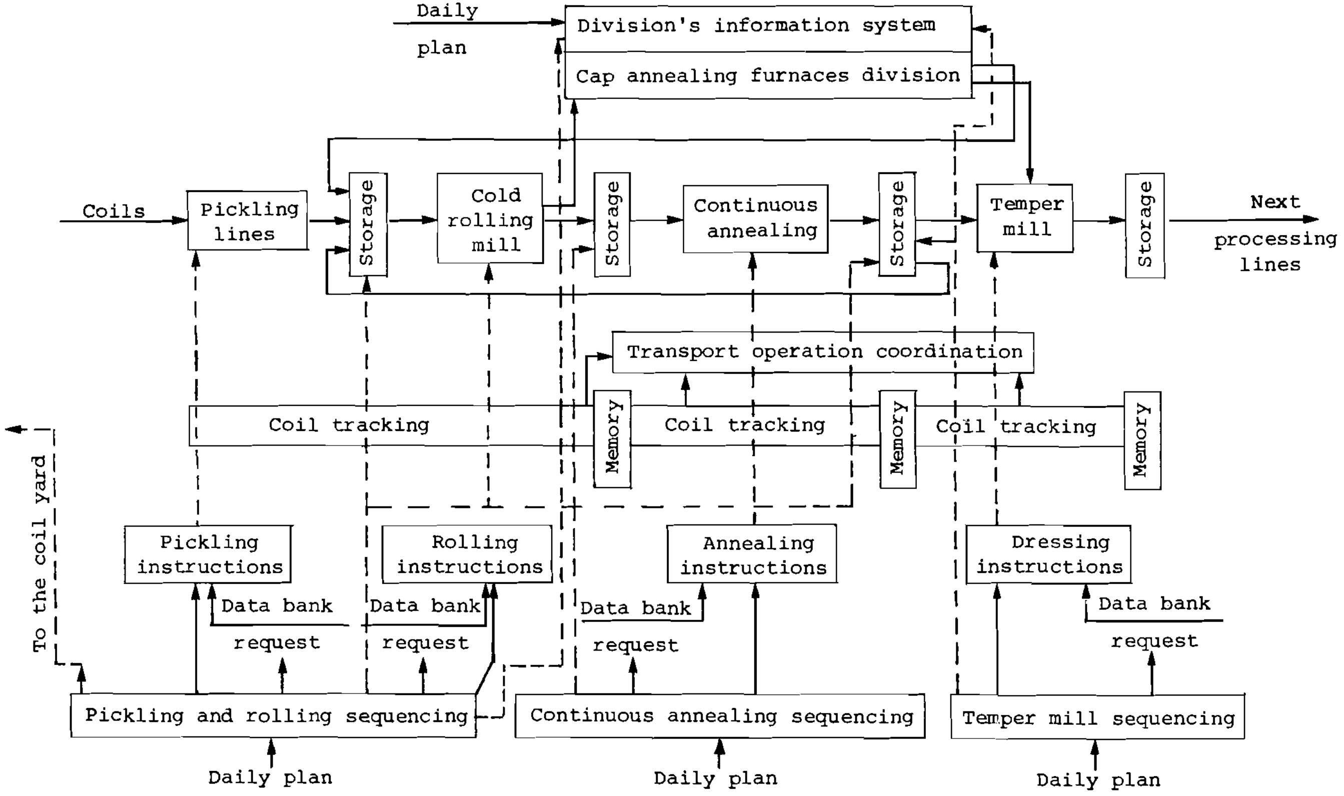


Figure 15. Diagram of cold rolling department material flow and operational control structure.

After being rolled, the strip goes first through annealing and then through a temper mill for "metal dressing" to obtain the required mechanical properties. If the order requires a thinner gauge, the annealed strip is passed on for secondary rerolling.

Annealing

Annealing facilities in the plant can be either continuous type furnaces through which the strip is passed or batch type cap furnaces. The latter operates in a cyclic manner with each cycle taking many hours.

The operational control system for a plant with continuous furnaces tracks coil movement from the rolling mill to the entry side of the furnace. It gives information to the furnace control system, such as what kind of annealing cycle should be performed. The continuous-type furnaces, like the pickling line, operate in a nonstop manner, and the entry and exit sides of the furnace are equipped with loop-type accumulators, shears, and joint-type welders. The operational system, which checks the movement of strip through the furnace, issues commands to the equipment on the entry side to weld the strips of two successive coils, and on the exit side to stop coiling, cut the strip and start a new coiling.

To compensate for possible imbalance of rolling mill and annealing furnace productivities (over short durations) there is an intermediate rolled coil storage on the furnace entry side. As is the case for the pickling lines and the rolling mill, the daily plan for the annealing furnace does not give the sequence of coils to be annealed in the continuous furnace. It is a function of the operational system to determine this sequence so as to minimize the number of coils in storage and to exclude the possibility of a coil shortage.

The batch-type annealing process using cap furnaces requires the scheduling of their operation over a much longer period than the cycle time. Usually, the works has both types of annealing facilities, and the furnace type to be used for strip of a particular order is selected beforehand during order processing, where all the technological routes are established. Thus, the coils to be sent to the cap furnaces are known in advance. Since the cap furnace cycle is longer than one day, the planning time interval for this division may be on the order of several days.

The daily plan, derived from this several-days' plan, represents the batch of coils to be charged to the furnaces and the batch of annealed coils ready for future processing. This plan considers the number of coils to be rolled after annealing; it is calculated in such a way that the total load is balanced for all the equipment for the day's duration. Thus, the operational control system need only determine the sequence of operations for the daily (or shift) plan; however, the cap furnace division should have a separate information system for continuous monitoring of the annealing process in each of the cap furnaces.

The same problem, namely sequencing over a short time horizon, is the task of the operational control system for all processing lines located beyond the rolling mill. The coordination of processing for a longer time interval must be tackled by the planning system. Thus, many of the processes in the cold rolling department can be considered as non-interacting in the calculation of sequences based on a day's plan. This means that the operational control system can be split into several parts, each of which can receive assignments from the planning system separately.

However, different coil transport operations may be performed by the same cranes and electrocars. To prevent confusion, the coordination of these transport operations should be performed by the operational control system. To do this, the system requires information about the location of transport mechanisms and the tasks they carry out, in the same way as in the stockyard.

The system should know the location of each coil in the storage area. This information can be fed into the system, either manually or automatically, using the principle described earlier for the slab yard, where feedback information is used to verify that commands issued by the system are correctly carried out. (For an electrocar powered by accumulators and having a large area of movement, this feedback can be obtained by a special induction system which tracks the movement of each car.)

Operational Control System Interfaces

The preceding examples of the operational control system show that each part of the system can operate separately if the initial information is available, and that this information provides the linkage between a given system and that of the previous stage. Thus, the primary rolling system receives its initial information from the steel making plant; the steel making plant receives it from the daily plan assignment which is prepared by the production scheduling system. But the schedule may be revised by the steel making operational control system in case of a failed heat, or in case of changes in the situation in the steel making shop or the soaking pit division. Rescheduling is done by the operator who receives all the information required for his decision making on a display unit.

The primary rolling operational control system also prepares the information required for decision making relevant to the heat delivered from the steel making plant. The scheduling of the soaking pits can be done fully automatically but the operator's confirmation is required.

The slab yard operational control system receives its initial information from the primary rolling system and from the rolling mill operational control system, which estimates the slab delivery schedule (except for the heavy plate mill whose operation is scheduled by the works production planning system).

The secondary rolling operations are more independent of previous production stages because of the presence of storage yards, that form a buffer between the primary and secondary rolling operations. Interconnection of their operational systems is performed through the production planning system, that prepares coordinated schedules with time horizons of one day or more (depending on the average time required for the hot rolled metal to be ready for the next stage of processing), and this tends to minimize the stock in the yard. The same situation exists in the cold rolling department which is connected with the hot strip mill through the hot coil yard (where the coil cooling time is of the order of several days).

It is interesting to note that the operational control system for the cold rolling department is split into several subsystems corresponding to different time scales, and interconnected through the daily plan prepared in advance by the production planning system. Thus, the operational control systems are linked through the on-line information system (connected with the material flow) and through the production planning system (when the material processing time is of shift duration or longer).

Monitoring of process performance and coordination of the various production units have a great influence on production efficiency by decreasing equipment idle time, speeding up process flows, and decreasing the incidence of failures of production operations. In addition, by achieving a smooth production process flow and by better coordination of the technological conditions, the product quality is improved over that already obtained through the local process control system. Finally, application of the operational control systems to the semi-finished and finished goods storage yards greatly improves the organization of material handling and thus helps to reduce inventory levels.

INTERPRETIVE AND CONCEPTUAL ASPECTS OF THE STATE-OF-THE-ART SURVEY

Motivation for Steelworks Computerization and Integration

The steel producer's environment consists of capital resources, manpower availability, raw material availability, demands for steel products, market situation, and geography. Each of these factors influences the type of steel making organization required for successful operation, and this in turn affects the type of system for planning, scheduling, and control best suited to the company's needs. In many cases, the environment is not constant; for example, the demands for steel may vary from time to time, and consequently the ideal system must be capable of adapting to the changing circumstances.

Fully computerized works may be more economic than manually operated plants for the following reasons: fewer employees, higher equipment productivity, decrease of inventory stock, improvement of delivery dates, ability to handle small orders, product quality improvement, and so on. These factors are particularly important for steel companies operating in a market oriented economy, owing to the competitive situation. But the additional cost of a fully computerized works is very high and this cost must be considered in the evaluation of alternative systems.

Capital Resources

The amount of capital available to a company is a function of the total resources available in the country and the business health of the particular company. A restricted availability of capital may have a major influence on systems design and implementation. Thus, in many cases, the level of automation and computerization is purely an economic problem which is greatly affected by world-wide competition.

Manpower Availability

Many companies may appear to be moving toward a higher level of automation solely in order to save manpower. Undoubtedly, this is a motivation in countries where manpower costs are high but it is by no means true universally, nor are costs the only reason for replacing man by machine.

The large new works capable of producing 10 million tons or more per year are being built in areas where there are insufficient numbers of people, let alone suitably experienced people, to even contemplate their being staffed for manual operation. These highly automated works require far fewer workers skilled in the steel making art and the main manpower problem is resolved by hiring young college graduates to operate and to maintain the computerized systems.

Considering existing steelworks of small and medium capacity, these have been in the past predominantly manually controlled. The trend is clearly toward more and more computerization, starting with the control of the technological processes, and extending to computer applications in the fields of management information and operations control. This situation is most typical to companies in the USA and Europe.

In some cases, companies computerize their plants because they cannot recruit and retain sufficiently experienced staff and because performance suffers through the need to continually train new staff. With a computerized plant, the very best practice can be built into computer programs and control systems and a consistently high standard of performance can be maintained.

Raw Material, Energy, and Fuel Availability

The situation with material, energy, and fuel provision is quite different at different works and whatever is costly and/ or represents a significant expenditure will attract the attention of efficiency seekers. For example, many companies employ sophisticated selection and transportation cost minimization programs to determine a lowest possible cost solution to the problem of obtaining adequate quantities of suitable ores. There are examples of computer controlled distribution and usage of electricity that results in avoidance of penalty charges (for highly fluctuating loads) while still maintaining high production rates.

Countries lacking iron ore and coal must import these resources, often from great distances, and, hence, must compensate these additional costs by improving production efficiency in order to remain competitive with steel manufacturers in other countries. Thus, a country like Japan, not having its own raw materials for steel production, has developed the most advanced computerized steel plants.

Demand for Steel Products

The manner in which a steel company receives orders for its products varies a great deal, and ranges from a fully planned situation, with a horizon of perhaps one to several years, to a completely free, competitive market situation. In the completely planned situation there is a little need for a rapid response to, for example, quoting competitive delivery times. There must still be an efficient order entry system but speed is not a prime requirement.

For steel manufacturers in a market oriented economy, computerization is needed not only to improve the production efficiency but also to achieve prompt and effective processing of received orders. A potential customer can inquire of several possible suppliers about price and delivery date. Any company that responds slowly to such requests is liable to find the order already has been placed elsewhere. An order inquiry and order entry system for such companies must work quickly and reliably. That is to say, an offer of price and promised delivery date must be available almost immediately and the likelihood must be very high that the delivery promise will in fact be met.

Geography

The location and distribution of steelworks within a company mostly affect communications, both physical movements and information transmissions, and will also have an influence on the level of computerization. The planning and control systems must operate with a speed and accuracy compatible with the company's environment and needs. For example, a company that is physically dispersed, for example, a head office in the capital and plants in remote industrial areas, must ensure that there is a means of rapid data processing and exchange of information between the important offices and functions.

The complications of scheduling product shipments depend on the geographical distribution of customers and the mode of shipment. Thus, if a company delivers most of its products by boat, the system that ensures that there is full boat load scheduled and that items are actually at the dock side at the proper time for loading must work to a higher standard of precision that the delivery system for a company using trucks for delivery by road.

Summary

As can be judged from the above discussion, there are a number of motives for the computerization and integration of steelworks. No general rule can be suggested for the decision making concerning the degree of computerization, but the premise is that a company will be encouraged toward increased computerization if a) demand is greater than capacity, b) manpower is expensive or limited, and c) it is market oriented in which case production efficiency and the speed with which an ordered item moves through the works are important. In general, there is a trend toward more extensive and more sophisticated computerization of the steel making system ranging from plant level control continuing through to management information and decision functions.

Performance of the Production System

The performance of the production system is based on four main phases:

1) estimating of product demand and analysis of the economic situation;

2) product design and design of the production facilities;

3) production planning, considering the existing plant facilities;

4) operation of the production processes.

The first phase is characterized by the long-term product demand forecast and is based on detailed investigations of the market situation and its trend. The economic analysis is performed considering the forecast demand, and the long-term economic policy of the company is formulated. Final assignments for the production system are then estimated in accordance with this policy. The first phase is usually of the form of economic planning without detailing the product types. In socialist countries having a planned economy, this phase represents a part of the inter-key-industries balance plan which is based on the long-term national economy development plan. Thus, this phase is not connected directly with the production process and therefore is not considered in this review.

The second phase has as its aim the equalization of production facilities with the demand through construction of new production facilities or modernization of existing facilities to meet the production assignments. It is also characterized by long-term horizons and high costs of implementation. Product design can also be related to this phase. In most cases, however, the time required for this part of the task is much smaller than that required for the design of the new production facilities. In addition, if the products are changed very often, their design is usually performed in line with the planning phase of the production process.

For steelworks, the products tend to be stable, and relatively few problems arise concerning new product design. On the other hand, the problems of production facilities design are very complicated and were considered beyond the scope of the present study. Consequently, the problems of the second phase have also been excluded from further consideration in this state-of-the-art review.

The third phase, that is, production planning, is connected with the prediction of the future production process flows to meet the demands. This phase is divided into several stages with different time horizons and different degrees of detail in accordance with the updating of information concerning demand, which is related to the actual orders received. At the last stage, the technological routing of the material processing--as well as the technologies of each process along the route--are defined and by means of production process flow prediction. The production plan is then based on considerations of existing equipment capabilities, process time constraints, product delivery dates, production costs, and related factors.

The fourth phase, production process operation, can be considered as the organization of the processes according to the preselected technological routes, and the coordination of the different process operations in order to minimize the effects of various disturbances that may have occurred during the production process flow. The organization of the process means presetting the equipment in accordance with the predetermined technological instructions and starting the processed material flow through the predetermined technological routes.

Production Planning

Planning Hierarchy

One of the main difficulties in compiling production plans is the uncertainty of the available information; this uncertainty tends to increase with increasing planning time horizon. To overcome this difficulty in part, the planning phase is divided into several stages, each with a progressively shorter time horizon, thus forming a planning hierarchy. The main underlying characteristics of this hierarchy are that it takes available data into account in time to consider several allocative strategies; it updates plans on a time scale that reflects the availability of further or more accurate data; it transforms plans into working schedules as orders are received, and instructs the plant processes accordingly.

The time periods associated with the different stages of the hierarchy are related to the times required to fulfill the planned actions (for example, order raw materials and semifinished products, equipment preparation, labor training, and so on). The planning hierarchies used by different steel producers are very similar, although the level of detail varied between different systems. There are three main points of divergency among existing systems:

a) the so-called medium-term planning is found only in enterprises that prepare less formal long-term plans and can be viewed as a refined and more detailed version of the first several years of the long-term plan;

b) the transition between the annual and the monthly production plan tends, in practice, to be gradual rather than a step function. The points in time at which enterprises make a formal restatement of the plan varies;

c) the steel making process is often considered the critical process when transforming an allocated production plan into individual process schedules. Prior processes like the blast furnace tend to work steadily at rates changed only occasionally. The basic steel making schedule is based usually on some fraction of a month, ranging from 7 to 14 days, with some plants preferring 10 days.

Table 1 gives the main planning timetable and time scales. On the annual repetition frequency, the activities are performed in the sequence: long-term, medium-term and annual planning so as to allow each successive planning activity to be a development and refinement of the previous one. Thus, the planning process as described is essentially feed-forward in nature. There are feedbacks, however, that derive from actual plant capabilities, operating rates, efficiencies, costs, etc., that might quantitatively alter possible production plans. These feedbacks are also manifest through updating of the planning models.

Since during this stage no detailed demands are available, the models used to create the plan are of a highly aggregated mode. To explain the nature of the model aggregation, let us consider the part of the steelworks shown in Figure 16. This part includes the steel making plant, stripping bays, soaking pits, slabbing mill, slab yard, and hot strip mill. Depending on the thickness, width, and steel grade of the strip, the output of the mill may vary by a factor of almost two.

The output of the slabbing mill is a function of ingot type, steel grade, slab size, and temperature of the ingots being charged to the soaking pits. Thus, for example, if the pits are charged with cold ingots delivered from the ingot yard, the heating time may increase up to four times.

These variations in the outputs of the different production stages make planning most difficult, since to ensure the production process flow, it is necessary to equalize the outputs of the stages connected in series. The presence of buffer storages between the production stages makes this equalization more easily achieved (if we consider planning over long enough time intervals). Thus, if we consider the monthly plan, the percentage of cold ingots charged to the pits is stable and repetitive for this time horizon. Also during this time horizon, the slabbing mill tends to roll ingots of different types in the same proportion and the averaged mill output can be considered stable. The output of the steel making plant may also be considered constant. This means that the models used for generating the monthly plan need to reflect only the averaged output for each stage of the production and not the fluctuation of the outputs which occur during the time interval.

Table 1. Planning hierarchy.

Frequency	Period Covered	Activity	Results
Ad hoc	Various	Business strategy	Basic guidelines
Annual	10-15 years	Long-term planning	Plant development plans, financing plans, long-term contracts, e.g., for ore.
Annual	5 years	Medium-term planning	Refined plant development plans, marketing strategies and budgets
Annual	1 year	Annual planning	Detailed operating plan and budget
Monthly	6, 3 and 1 month	Production planning	Increasingly firm production plans
Daily	Up to 3 months	Order entry, allocation to works	Works order file
Daily	Up to 14 days (depends on process)	Process scheduling	Sequence of processing instructions
Real time	Up to 24 hours	Operations control	Issue of instructions, tracking and receipt of feedback
Real time	Up to a few hours (depends on process)	Process control	Direct control of processing
Ad hoc (in real time)	Immediate	Rescheduling	Recovery from errors

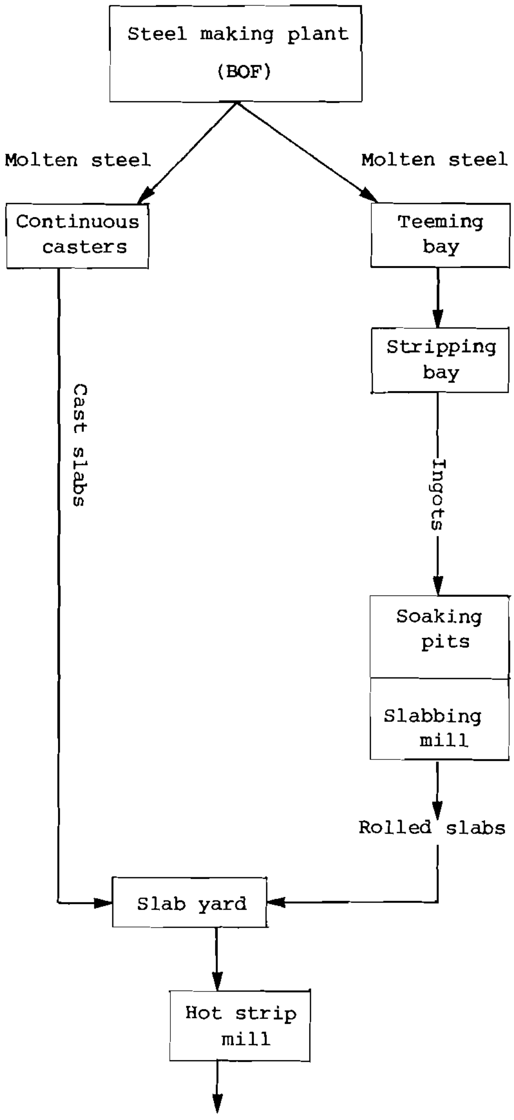


Figure 16. Block diagram of a part of the steelworks.

Since the final product is the hot rolled strip, its averaged output in tons per hour should not exceed the averaged outputs of the preceding production stages. These outputs can be found by statistical investigations of previous production performance by which the distributions of these outputs may be estimated. The variations of the outputs are caused by disturbances that influence the process and have broad frequency spectra.

It is obvious that the averaged or expected value of the output may be used as a planning standard only for a time horizon larger than that determined by the lowest frequency component of the disturbances. To determine this horizon, the disturbances' frequency spectra should be investigated. Methods based on spectral or correlation analysis may be useful here. However, these methods assume that the relative distribution of the demand, in terms of strip sizes and steel grades, is the same from one time interval to the next. When, for a given time interval, a new distribution is known the averaged output for this new distribution should be determined.

The output corresponding to all possible strip sizes and steel grades can be found from the results of previous mill operation. The data may be put in the form of a matrix with the element a_{ij} representing the mill output in tons per hour when rolling strip of i^{th} size and of j^{th} steel grade. The demand distribution can also be represented by a matrix with the element d_{ij} denoting the fraction of the total demand that is for strip of size "i" and grade "j". Thus,

$$\sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij} = 1$$

where n,m are the total number of strip size and grade categories under consideration, respectively. The averaged output of the mill in tons per hour may then be expressed as

$$P = \alpha \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} d_{ij}$$

where α is a coefficient that takes account of the decrease in output caused by roll replacement. If we now know the slab size required for manufacturing strip in each size and grade category, we can determine the averaged output of the slabbing mill. In a similar way, models may be developed for other stages of the production line.

As previously mentioned, the setting of production standards equal to averaged output values requires the provision of buffer storages between production stages; otherwise, there will be a high probability of failure of the plan to achieve production targets. For example, considering the material flow between the steel making plant and the soaking pit division, we find that if the plan is based on expectations of the soaking pit output, the probability of fulfillment of the plan may only be around 50% because the arrival times of new ingots may not coincide with the ready times of the pits to be charged. A delay in charging of the ingots will result in a drop in ingot temperatures, causing a subsequent increase in heating time (hence a reduction in the effective output of the division and an increase in fuel consumption).

In order to increase the probability of fulfillment of the plan, it is necessary to choose standards below the output expectations; however, a large reduction in standards leads to a lower use of equipment that increases production costs. On the other hand, failure of the plan achievement also increases production costs and the appropriate planning standard can be found as a trade-off between these two factors. Thus, the problem of the planning standards can be formulated as an optimization problem with the criterion of minimum production costs.

The above discussion relates to the problem of the limitations of the manufacturing facilities that should be considered. In cases where demand exceeds manufacturing capabilities, the production plan figures for a given enterprise are found to be equal to these limits. It is assumed that the company head office will select the more profitable parts of the demand as assignments to the works.

The model of a real process reflects only the "main" variables that influence the process performance; other variables, not considered by the model, cause variation of the model parameters. These parameters are usually evaluated to reflect the average or expected values of the neglected variables over the period of consideration.

The optimal production plan should give the changes of assignment for different production stages through time, and thus the plan can be considered as an optimal trajectory that brings the process state from one given point of many dimensional space to another given point. In general, the higher the dimension, for example, the more variables considered by the model, the more precisely the process trajectory can be defined. Since the production process is influenced by the environment whose behavior is of a random nature, many of the variables are random functions of time; hence, the production process performance simulated by the model is also a random function.

Obviously, the more variables that are included in the model, the less will be the deviation of the simulated from the real process. But increasing the number of variables and representing them by probability density laws is impractical because of the great increase in model complexity. Thus, the model used in practice has a limited number of variables, and the relations between them are of a deterministic nature, being estimated from statistical investigations of the actual past process behavior. The deviation of the simulated from the real process is considered to be caused by "disturbances" affecting the real process. These disturbances, as mentioned earlier, are random time functions with different frequency spectra. In many cases these disturbances are a result of periodic changes in characteristics of the technological equipment, for instance, changes induced by the wear and the subsequent repair or replacement of a piece of equipment.

An example of such a change is the variation of the hot strip mill output caused by the wear of the backup and working rolls. As mentioned previously, mill output varies by a factor of almost two depending on the steel grade and strip size. The reason for this variation is the need to roll progressively narrower strip as the wear of the backup rolls increases to ensure good strip shape. Thus, the 2,000 mm mill, after replacement of the backup rolls, can roll strips of 1,850 mm width; however, as the rolls wear down, the maximum width decreases to 1,000 mm. Replacement of the backup rolls is usually done after eight to ten days of continuous operation; thus the basic period of the mill's output variation is equal to eight to ten days.

Another cause of variation of the mill output is the wear of the working rolls, which are replaced after six to eight hours of continuous operation. Thin strip is usually rolled on the new working rolls and the strip thickness is increased with the rolls' wear. Thus, considering the roll wear as a disturbance, we find that the power density spectrum of the mill's output over time has at least two peaks: one corresponds to the backup roll replacement cycle, the other to the working roll replacement cycle.

Knowledge of the time behavior of the disturbances helps in creating models for the process performance evaluation for different time horizons. These models allow us to estimate beforehand the control actions to be taken in sequence corresponding to the different time intervals in order to obtain the optimal process performance. As shown, to create a model for a given time horizon, the time behavior of the disturbances should be investigated. In some cases, this can be done by considering physical phenomena (for instance, by the analysis of roll wear); in others, the process relations are obscure and statistical methods have to be used.

The variables included in the model should be such that, for a given time interval T, the deviation of the simulated process from the real one has an expectation that is negligibly small. We may often use simplified models with a small number of variables for a long time horizon with adequate precision; however, for shorter time horizons the disturbances may have frequency components low enough that their effects, averaged over the shorter interval, cannot be considered negligible.

The model for the longer time horizon is developed, not only by excluding the variables that do not influence the performance, but also by aggregating the remaining variables. Let us consider the control of the reheating furnaces. The model that is used for optimizing the metal heating process takes into account the variation of the furnace temperature during the heating cycle. But the model used for scheduling furnace operations does not include the furnace temperature as an explicit variable, since the temperature variations averaged over several heating cycles should have effectively zero expectation. For this latter model, one of the variables will be the heating cycle period, which is a function of the heating condition; changes in the length of the heating cycle are caused by variations of the mass and thermal properties of the metal charged in the furnace, that averaged over a long period of time, may be considered as having zero expectation. Thus, for a period of a month or more, the heating cycle time may be considered as a standard with respect to the monthly planning of the furnace operation.

Optimal Production Plan

The input to the production planning process is an estimate of product demand based on forecasts and on real orders. Assuming that the company has several works, the first step of the production planning is to allocate the manufacturing assignments of the estimated demand for the various product types among the steelworks in the amounts that will maximize company profit.

Consider a company with "m" works and "n" product types. If the estimated market demand over the planning horizon T calls for the manufacture of X_i units of the i^{th} product type, i = 1,2...,n, then the planning problem may be expressed:

$$\text{maximize } P = \sum_{j=1}^{m} \sum_{i=1}^{n} (C_i - b_{ji})X_{ji}$$

subject to the constraints

a) $\sum_{j=1}^{m} X_{ji} \leq X_i$ $\qquad i = 1,2,\ldots,n$

b) $\sum_{i=1}^{n} a_{ji}X_{ji} \leq T$ $\qquad j = 1,2,\ldots,m$

c) $X_{ji} \geq 0$ $\qquad$ for all i,j

where X_{ij} denotes the quantity of the i^{th} product type to be manufactured in the j^{th} works, C_i is the unit price of the i^{th} type product, and a_{ji}, b_{ji} denote, respectively, the time required and the production cost for manufacturing one unit of the i^{th} product type in the j^{th} works.

Constraint a) implies that the total assignments for manufacturing each product type should not exceed the estimated demand for that product. Constraint b) specifies that each of the works must complete its assignment within the period T. Finally, constraint c) states that no assignment can be negative. Note that the case where the j^{th} works is unable to manufacture product "i" is handled by making a_{ji} excessively large.

The stated problem is a linear one and to solve it linear programming methods can be applied. But in the many practical cases, the parameter values may depend on the production assignment (for example, a_{ji} may decrease with an increase of X_{ji}) and thus the problem becomes nonlinear which makes its solution more complicated. In addition, the assignment X_{ji} can be limited by technological restrictions which depend on some quantitative correlation of different product types to be manufactured in the j^{th} works. This constraint may take the form

$$d) \sum_{i \varepsilon S_{jk}} X_{ji} \leq A_{jk}$$

where S_{jk} denotes the set of product types associated with the restriction A_{jk}. Indeed, the most difficult part of the production problem formulation is the consideration of such production process constraints.

In the problem statement above, the costs of transporting products to the consumer have not been taken into account. In case these costs are significant factors influencing the company's profit or the assignment process, they should be included in the problem statement; this, however, increases the difficulty in solving the problem.

The planning procedure defined by the above problem formulation represents strictly centralized decision making. Thus, the decisions at the company level, in the form of production assignments to the steelworks, are based on overall company criteria that, in many cases, may conflict with the local works' interests (for instance, an assignment may include items that induce a high production cost or a low productivity of equipment.

In many of the companies visited, the criterion for production planning at the works level was the minimization of production costs subject to meeting the works production assignment set at the company level. Factors affecting these production costs include the duration of the production cycle, the stock of semifinished and finished products, the technological routing and operating instructions that affect energy, labor, equipment costs, etc.

The models used in the planning process are highly aggregated. Thus, although the number of distinct products manufactured by the steelworks is extremely large, the total number of product types explicit in the model, n, is relatively small, which very significantly reduces the difficulties of forecasting the demand and of solving the planning problem. By the same token, the parameters of the model represent aggregated average values of production costs, processing times, etc. These parameter values may be updated from time to time (often on an annual basis) based on accumulated statistics of recent plant performance. An adaptation of the model may also be invoked upon a change in equipment or some major change in operating practice.

To find the technological routes (considering technological limitations) that minimize the total production cost various optimization techniques can be used. To minimize the stock of semifinished products, the time schedules for production stages performed in series should be coordinated. To minimize the stock of the finished product, the production time schedule should be coordinated with the product delivery date. Note that the feasibility of the recommended technological routes have to be checked when coordinated schedules are created, since the selection of these routes is done without consideration of possible noncoincidences of the production operations.

Creation of the Production Schedule

The first stage of the scheduling is the "plant loading", which estimates the times required for the orders to be fulfilled through each stage of the selected technological routes. If the manufacturing time required for one of the stages exceeds the available working time, some of the orders have to be rejected from the assignment, or special measures should be taken (for instance, postponing equipment repair, ordering semifinished products from other plants, prolonging the work shift, etc.).

The plant loading is determined for a time horizon corresponding to the planning time horizon. For instance, if the assignment from the company head office is based on a time horizon of one month, then the plant loading is made on the same time interval and represents the detailed production plan of the steelworks for the month. In most cases of existing practice, the monthly plan is divided into a sequence of weekly plans which, in turn, are divided among the days of the week. The daily quantification may then be further divided into shift and hourly schedules, etc., reaching finally the detailed sequencing of the production operations.

The scheduling time horizons should be selected in accordance with the frequency spectra of the production process disturbances. As an example, we can take the scheduling of the hot strip mill which is influenced by two periodically repeated "disturbances" caused by the wear of the backup and working rolls. Since the plant loading is based on the averaged output of the mill, the minimum time horizon for this loading must be equal to or a multiple of the period between backup roll changes. Thus, within this time horizon, the scheduling should estimate the sequence of orders to be rolled. This sequence gives the assignment schedule for the steel making plant which must be coordinated with the mill schedule in such a way that the stock of slabs in the yard will be minimal.

The loading requirement for optimal operation of the hot strip mill is adopted because the cost associated with this operation is much higher than that of the steel making department, and thus has a much greater influence on the total production cost. The mill operation schedule is based on data from the orders to be manufactured during the given time horizon T (see Figure 17), and on the roll wear model. By means of this model, permissible roll wear can be estimated as a function of the type and quantity of strip already rolled. Further, the model provides the means for determining the sequence of orders to be rolled on a given mill in order to minimize the average number of roll changes over the period T.

Let us assume that the plant loading procedure determines the set of orders Q that are to be rolled on the hot strip mill during the time interval T. Since the strip width should be decreased as the wear on the backup rolls increases, the elements of Q must be ordered according to strip width. In particular, in order to produce good strip, it is necessary to predict the wear of the backup rolls as a function of the length of strip rolled and its width.

Let x_i, $i = 1,2,\dots,n$ denote the length of strip of width "i" rolled since the last replacement of the backup rolls, c_i denote the roll wear coefficient (amount of wear per unit length of strip rolled), and d_i denote the maximum roll wear permitted for strip of width "i". Assume that $i = 1$ corresponds to the widest strip to be rolled and that increasing values of i relate to strip categories of decreasing width. Then the constraint caused by backup roll wear may be formulated as

$$\sum_{i=1}^{j} c_i x_i \leq d_j \qquad j = 1,2,\dots,n \quad .$$

The vector $(x_1, x_2,\dots,x_n)$ which satisfies the above constraint represents the permissible rolling schedule for the time interval between two successive backup rolls replacements.

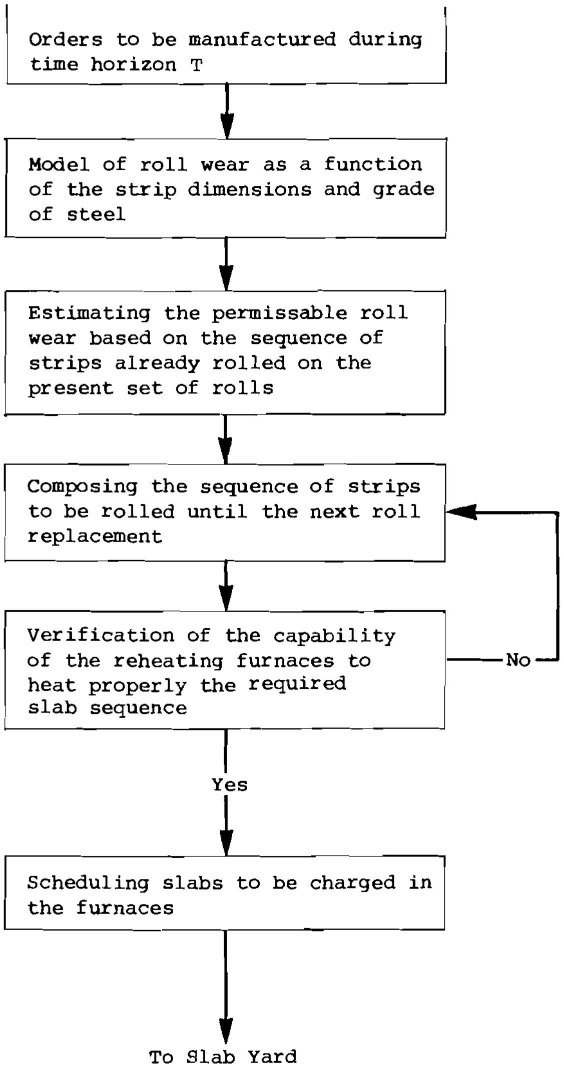


Figure 17. Hot strip mill scheduling procedure.

In general, the set Q will contain more orders than can be rolled within a single period. The above procedure can be extended to generate a matrix of rolling schedules covering K backup roll replacements. An objective is to determine the schedules resulting in a minimum number of roll replacements, corresponding to minimum mill idle time. This problem can be solved by linear integer programming methods.

The next problem is to estimate the rolling schedules after every replacement of the working rolls. These schedules should guarantee a minimum number of these replacements, thus minimizing the mill idle time as well as minimizing the costs connected with replacing the rolls.

This problem may be formulated in a very similar way to the one above. Thus, we may formulate the constraint associated with working roll wear as

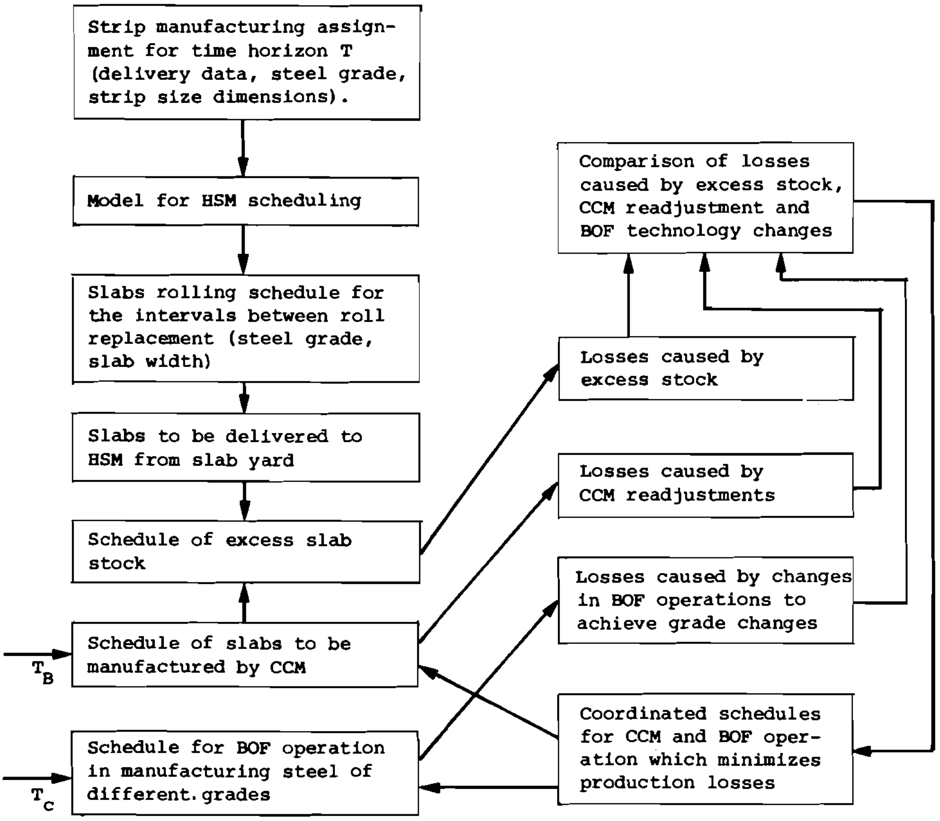
$$\sum_{i=1}^{j} c_i^* x_i^* \le d_j^* \qquad j = 1,2,\ldots,m$$

where x_i^* denotes the length of strip of thickness interval "i" rolled since the last working roll replacement, c_i^* is the roll wear coefficient per unit length of strip rolled, and d_i^* denotes the constraint for the i^{th} thickness category. Here i = 1 denotes the thinnest strip, i = 2,3,...,m denotes strip of increasing thickness. Thus to estimate the rolling schedule for the hot strip mill, two time horizons are involved, each with a different model. The schedule of the mill operation should require delivery of slabs to the mill furnaces in their proper sequence and timing.

Slabs can be delivered to the slab yard from either the slabbing mill or the continuous casters of the BOF plant. Since the mill rolling schedule calls for slabs of different widths, the slab manufacturing schedule in order to minimize the slab stock, should follow the sequence required by the rolling mill schedule in order to maintain the number of slabs stored in the slab yard at a minimum. Width changes can be achieved more easily on the slabbing mill than on the continuous casters, since readjustment of a caster is a costly and time consuming job.

Figure 18 shows the decision-making sequence in preparing the coordinated slab manufacturing schedule. As can be seen from the figure, the coordinated schedule considers the losses caused by an excess of slab stock, readjustments of the continuous casting machine, and grade changes on the BOF.

The latter losses are of a probabilistic nature since they are a result of the failure of a heat to meet required steel grade standards following a change in BOF technology. To reduce the probability of failure, the same steel grade should be produced



T_B - BOF cycle time

T_c - Heat casting time (T_c is a function of slab size)

CCM - Continuous casting machine

HSM - Hot strip mill

BOF - Basic oxygen furnace (steel making)

The interval between roll replacements defines the minimal scheduling time horizon.

Figure 18. BOF and CCM scheduling procedure.

in successive heats. If the hot strip mill schedule requires slabs of several different steel grades, these can be manufactured in advance, thus reducing the number of grade changes at the expense, however, of an increase in losses caused by excess stock. Since the slabs delivered from the BOF plant usually require surface repair, which takes some time, the slab manufacturing schedule should be shifted in time relative to the rolling schedule in order to achieve minimum slab stock level.

When the slab manufacturing facilities supply slabs to only one hot strip mill, and these facilities are equal to the average mill productivity, some slabs stock must be provided as a buffer between the steel making plant and the rolling mill. But usually steelworks have several rolling mills receiving slabs (or billets) from the same steel making plant, and rolling schedules for these mills should be coordinated in such a way that the fluctuations in total mill output will be minimal.

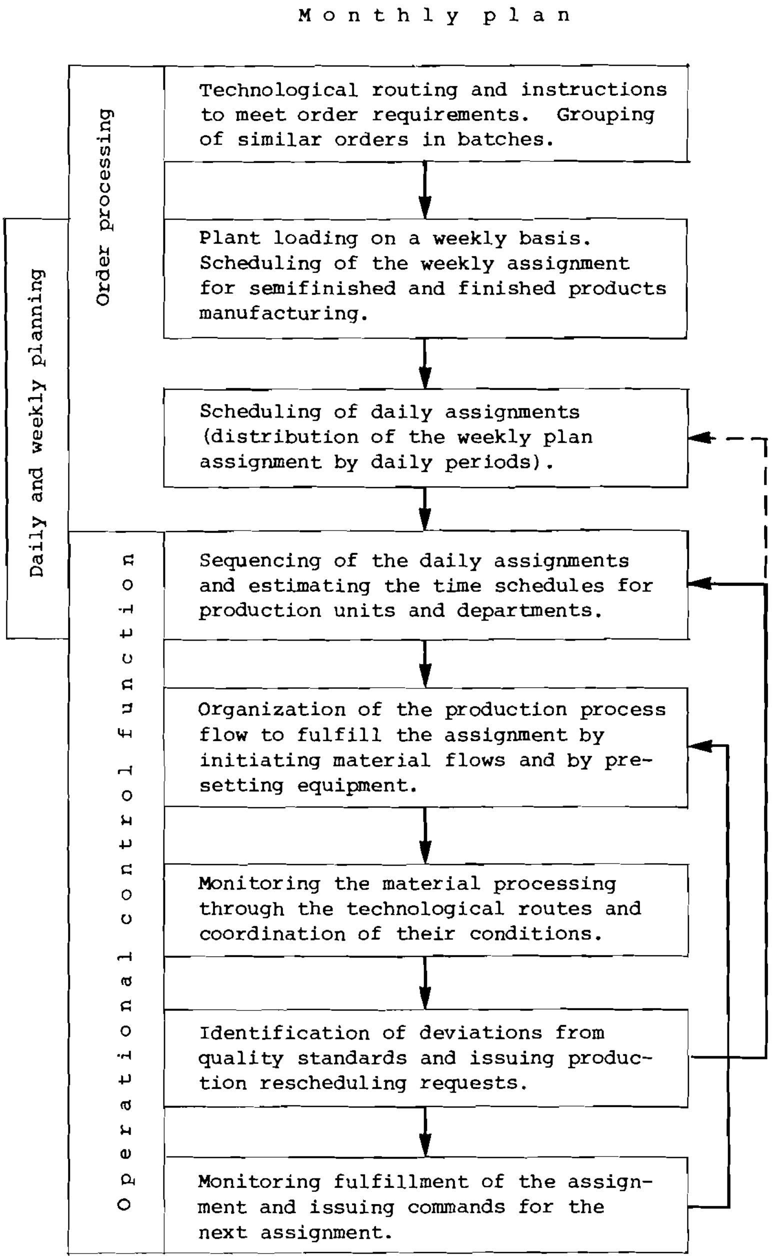
At the steelworks we visited, solutions to the scheduling problems described above are performed "manually" on the basis of the heuristic rules found by experience. The above formalized concepts were developed on the basis of an analysis of these experiences, and their practical application required a good deal of research work.

Operational Control

The production process operational phase involves the implementation of the plans and schedules, and it is carried out by the operational control system. The functions of this system are shown in Figure 19. The system works in real time and receives information directly from the shop floor. Figure 19 presents some of the functions that belong to the planning phase, but which are closely related to the operational phase (assignments in the form of the technological routes and instructions).

The technological instructions are generated on the basis of nominal or standard process conditions; the fulfillment of these instructions gives the required process performance only when the actual and the standard process conditions are equivalent. However, the real process is always subject to disturbances that influence plant performance. To eliminate or to minimize these disturbance influences, two strategies can be used. According to the first strategy, the observed deviation generates an action that changes the flow of energy or material in a way that tends to reduce the deviation. The second strategy calls for revision of the previously estimated plan, considering the cost of this revision and, thus, finding a new optimal process trajectory.

The weak point of the first strategy is that it does not consider the costs of the additional action and of the resources used to achieve this action. If these costs are significant,



Technological routing and instructions to meet order requirements. Grouping of similar orders in batches.

Plant loading on a weekly basis. Scheduling of the weekly assignment for semifinished and finished products manufacturing.

Scheduling of daily assignments (distribution of the weekly plan assignment by daily periods).

Sequencing of the daily assignments and estimating the time schedules for production units and departments.

Organization of the production process flow to fulfill the assignment by initiating material flows and by presetting equipment.

Monitoring the material processing through the technological routes and coordination of their conditions.

Identification of deviations from quality standards and issuing production rescheduling requests.

Monitoring fulfillment of the assignment and issuing commands for the next assignment.

Figure 19. The scope of the operational control function.

the estimated "optimal" trajectory can be far from really optimal. Thus, only in the case of low cost of the additional action and short duration of the disturbance is the first strategy suitable.

The weak point of the second strategy is the assumption that the observed disturbance lasts until the end of the planned interval. If this disturbance lasts only a short time, the newly found optimal trajectory must again be revised and so on. When it is possible to predict the time characteristics of the disturbances, both strategies can be used according to these characteristics. In general, the effectiveness of the second strategy depends greatly on the degree of correspondence of the model to the real plant. This correspondence can be increased by model adaption.

The adaptation of models makes them reflect more closely the real process and thus transfer the nonstationary ranges of the predicted process flows to quasi-stationary ranges. The control achieved by the adapted model reduces the dispersion of the aggregated variables, which are used by the models of the upper levels, and thus facilitates the planning of plant production.

Depending on the nature of the deviations of the production process, the first strategy may not be sufficient to eliminate the deviations, and rescheduling may be required. However, since the production stages are interconnected, the rescheduling of one stage may require the rescheduling of all the others. Thus, it is preferable to use the first strategy, if it is feasible and if this avoids the need for total rescheduling of the production process.

This remark can be related to stable processes (or processes made stable artificially) for which the production schedule is prepared during the planning phase. For instance, in heavy plate production (see the second section), slab sizes are precalculated during the "order processing" stage, and each slab has its own destination flow that results in a minimum waste of metal in the shearing operation. In the case of a rejected slab, a new planning cycle must be initiated starting from the "order processing" stage, considering the repeat rolling as a new order.

Where the incidence of rejects or production failures occurs rather often, the detailed scheduling should be performed each time such a failure is revealed. For example, in the steel making plant, the miscarrying of heats (owing to not obtaining the required steel grade) occurs often and, therefore, the detailed scheduling of the primary ingot rolling is done for only a short time horizon. Since this time period does not usually exceed the normal time duration of the ingot heating cycle, the schedule prepared for this horizon can be revised, as necessary, after each new heat is produced by the plant. Thus, a heat that is produced out of schedule can often be reassigned by revising the daily (or shift) plan assignments for the rolling operations. In case there is no suitable assignment, the heat is sent to the cold yard. Since the miscarried heat had been destined for some specific order, the heat for the required grade of steel must be rescheduled, and the substituted heat deleted from the assignment.

Process Coordination

The function of process coordination may be explained by the following example from the second section. A modern hot strip mill is capable of rolling with speeds up to 25 meters per second; however, the actual speeds that can be used are much lower because of the limitation imposed by the final rolling temperature, which affects strip quality. Thus, the heat losses during the rolling of thick strip are much lower than for thin strip; hence, the rolling speed may have to be reduced by a factor of two or three in order to maintain the final strip temperature within the required limits. This has a great influence on the mill production efficiency.

This efficiency can be improved through the proper coordination of the temperature control of the slab reheat furnaces and the roll settings on the mill. Specifically, as the required strip thickness increases, slab temperature should be reduced, and the roll settings should be distributed in a way that tends to increase the proportion of metal reduction in the first stands (within allowable loading constraints). This coordination should be done on-line in order to consider the actual condition of the slabs leaving the furnaces.

The result of this coordination greatly depends on the sequencing of the slabs assigned for rolling strips of different thicknesses. Consequently, in defining this sequencing, the special requirements of the coordination feasibility must be considered.

Operational Phase

As can be seen from Figure 19 one of the functions performed in the production process operational phase is to monitor the completion of each item of the schedule. After fulfilling the material processing requirements for a given item in the production schedule, the production process must be reset in accordance with the requirements of the next item of the schedule. Continuous monitoring and accounting of the processed material flows are maintained to establish the moment that the production process switches from one technological instruction and route to the next.

The monitoring also reveals any deviation of the production process from the schedule and, thus, may initiate a coordination of a rescheduling of the processing stages. To reveal such deviations as soon as possible, simulation models are used to provide a fast-time prediction of the process flows. For example, by predicting the ready time of ingots in the soaking pits, the primary rolling operational control system can estimate a possible rolling mill idle time or an overheating of ingots. The operational control of the steel making plant can minimize converter idle time by predicting in advance the raw material flows and the readiness of the auxiliary equipment (teeming cranes, molds, ladles, and so on).

Design and Implementation of the Integrated Systems Control

The integrated systems control of steel making covers a broad scope of functions of different natures and requirements. To create a process control system for a production facility usually requires a deep knowledge of the underlying technology, and these systems are often designed by the manufacturer of the technological equipment together with the manufacturer of the control equipment.

The development of a planning system should involve a specialist familiar with the capabilities of the technological equipment and with the various possible routings for the material processing. He need not necessarily be deeply acquainted with the processes themselves, but should have a good knowledge of the specific features for a given plant and experience of its general environment.

To design an operational control system for different production stages, it is necessary to be a specialist in the production process organization with a good knowledge of all possible situations that might occur during plant operations as well as the ways that decision making may improve the situation. His knowledge of the process control should be rather good, particularly with respect to the restrictions and limits of the process performance.

The differences in the approaches to the above mentioned problems and the frequent underestimating of the interface problems are often reasons for failure of the integrated system design. This is particularly true in the case of computerization of existing plants because of conservatism on the part of the plant's staff accustomed to the previous control methods and strategy. There are fewer such problems for a new plant, but other difficulties may arise, for example, the lack of experience in solving some of the managerial problems.

When a system for a new plant is under design, it is very helpful for the construction stage and the operational stage to be achieved through several steps. For instance, during the first step, only the blast furnace is put into operation. Then the steel making plant is erected and the next part of the system is put into operation, and so on. Thus, long time intervals are available for the revisions of the previously designed parts of the integrated system.

It is interesting to note that even after the entire system has been in successful operation for several years, there are always modernizations and improvements of the system's functions that can be incorporated. To accommodate these modifications, the ability to extend the hardware capability should be foreseen at the initial design stage. The decision is often made to rent rather than purchase the computer in order to provide flexibility in this regard.

The existing and successfully operated integrated control systems have been designed and implemented, in their main parts, by the steelworks' staff, rather than by instrumentation or computer manufacturing companies. These companies can supply the hardware and software for the local process control systems and the hardware and computer internal software selected by the designers of the integrated system. However, the latter have to develop all the algorithms and the necessary programming for the computers, and to determine how to structure and organize the system (for example, how to divide the tasks between man and computer).

Resulting Efficiency of the Computerization

Depending on the time horizon considered, the planning stages are done either in the company head office or by the works within the company. Usually, long- and medium-term planning include an annual planning review performed by the head office, since this concerns the allocation of a company's limited resources (such as investments, raw material, fuel, etc.). Note that the same considerations arise in socialist countries where the steelworks belong to the government.

To solve the resources allocational problem without considering how these resources will be used, for example, without consideration of the production assignment allocation, makes no sense. Thus, the company head office prepares the production assignments for each steelworks in a way that will be most effective with respect to overall company objectives, for example, to maximize company profits.

The production planning performed by the works usually has a time horizon of not more than a month, and the criteria for this planning are quality improvement and minimization of production costs. Thus, in the scope of the company there is a form of centralization which is very close to the centralization of the planning in the socialist countries.

There is also a very strict centralization of the control at the steelworks level. The whole production planning procedure, for a month time horizon or less, including order processing and scheduling, is performed in a centralized manner, eliminating the necessity of having separate small production planning departments on the shop level. In addition, with the help of computers, this planning requires only a few people. Combining the planning/scheduling procedure with the operational control means that only shift teams need to be on the shop floors, with considerable reduction of the steelworks' staff.

The total reduction of the number of steelworks' employees achieved through a computerized and integrated control system results in very high productivity levels. Thus, in some Japanese steelworks, productivity figures of 750 tons steel per employee per year are reported, almost 2.5 times that for works in Europe and the USA.

In addition to manpower reduction, the integrated system provides increased flexibility for operations and responsiveness, for example, permitting the handling of small orders, reduction of delivery time, decreased stocks of semifinished and finished products, reduction of material waste, improvement of product quality and a general increase of productivity.

INTEGRATED SYSTEMS CONTROL APPROACH

The material of this section serves to provide the analytical background for interpretation of the state-of-the-art study of integrated systems control presented in this Review. It also provides the basis for a conceptual framework upon which experiences in the steel industry may be generalized to serve a broad class of industrial production systems.

We adopt, for convenience, the term control to mean generically all aspects of control and decision making that are applied to the system operating in real time, for example, planning, scheduling, operations control, process control. The common characteristic of the control function, in the sense employed here, is the basing of actions, responses, decisions, etc., on information describing the state of the system (and its environment) interpreted through the medium of appropriate models relevant to system performance. By the same token, we will use the label controller to denote the means or agent by which the control/decision-making functions are carried out.

Basic Elements of the System

With respect to decision making and control, we distinguish five basic elements of the system, identified as: plant, environment, performance evaluation, controller, information processor.

The articulation of these elements is shown conceptually as Figure 20.

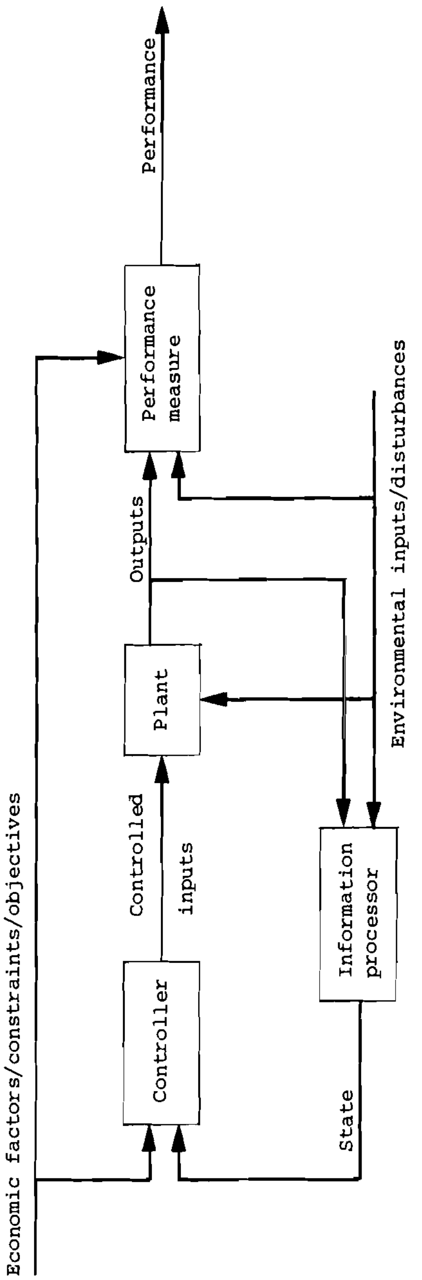


Figure 20. Block diagram of basic system.

Plant

The term plant is used here to denote the controlled system or means of production. It may refer variously to a processing unit, a mill, a works, or even the company, depending on the level of control being considered. We assume that the plant is governed by causal relationships; that is, its behavior, relevant to our control objectives, may be described (in principle) by a set of input-output relationships. We assume further that some of the plant inputs are free to be selected by a decision maker or controller so as to influence the plant's behavior in a desired direction. Thus, we may classify the variables associated with the plant as follows.

1) Disturbance inputs: these are inputs that represent the effects of interactions of the plant with its environment. In general, a disturbance input causes the plant output to deviate from desired or predicted behavior and hence motivates control action. Some examples of disturbances are:

a) A change in ore composition may affect the operation of the blast furnace and require changes in operating conditions of the furnace to maintain production standards. The composition of the output of the furnace may also be affected; the resultant changes in iron composition will then represent disturbance inputs to the subsequent steel making process.

b) The receipt of a new order may constitute a disturbance with respect to the scheduling operation if the order is of sufficient urgency and priority to require a modification of the previously determined schedule.

c) A change in the size of slabs entering the reheat furnace will affect the heating pattern and may call for changes in the temperature settings of the various zones in the furnace in order to ensure that the slabs exit the furnace at the proper time and with the required temperature distribution.

d) A delay in the availability of a soaking pit for charging of new ingots may affect the heating time and firing of the pit; it may also affect subsequent pit scheduling and mill throughput.

We also recognize a special class of disturbance that we call contingency occurrences. These refer to events, occurring at discrete points in time, that signal that the system is no longer operating according to assumptions implied by the current control or decision-making models. As a result, it is necessary to change the control objective, go into a new control mode, modify the structure of the system, or develop some other non-normal response. For example,

a) The breakdown of a piece of equipment may cause the shutdown of the production unit it serves. This event may impact other units in the chain as well, necessitating routing and scheduling changes which may be more or less extensive. The local control objectives may change from say maximizing throughput to minimizing the time required to get back on stream.

b) A failure of the finished product to meet order specifications will induce effects throughout the system as a result of efforts to redo the order and to reassign (or recycle) the "off-spec" production.

c) Disruption of the flow of some raw material, say coal, through strike action may, depending on the duration of the strike, affect the entire spectrum of decision-making functions from planning to operations.

We comment that while the compensation for disturbance inputs may be carried out either manually or automatically, the handling of contingency events is almost always under human supervision, even in the most advanced current systems. Indeed, as the system becomes more automated, the role of the operator focuses more and more on his responsibility for detecting and responding to contingency occurrences.

2) <u>Controlled inputs</u> (or decision variables): these are the results of the decision-making or control process carried out by the controller with respect to the plant. There are a variety of ways that these results may be communicated to the plant; in general, they modify the relationships among the plant variables through physical actions on the plant performed either directly or indirectly. As examples, we may cite:

a) Varying the fuel flow to a furnace changes the energy balance in the furnace, thereby causing the temperature to change in a desired direction.

b) Varying the feed rates of various ores and coke supplied to the blast furnace affects the material balance in the furnace which in turn affects its performance and the composition of the pig iron product.

c) Changing the roll displacement on the rolling mill changes the compressive forces acting on the steel strip and consequently the strip thickness.

d) Changing the sequence of slabs being rolled may affect the delivery date of a particular order as well as the performance of the rolling mill and subsequent operations.

3) <u>Outputs</u>: these are variables of the plant which are:

a) functionally dependent on the designated input variables;

b) used by the controller in determining its decision or control actions;

c) are relevant with respect to the evaluation of plant performance or the assessment of the effectiveness of a particular policy or action;

d) are available as explicit values or functions of time either through direct measurement or through inference (via a model) from the measurement of other variables.

For illustration, we may consider furnace temperature as an output variable in the problem of temperature control of the slab heating furnace. The temperature is dependent upon the firing rate (controlled input) as well as various load disturbances (changes in slab dimensions and thermal characteristics.) In particular, the furnace temperature can be measured by means of a thermocouple or radiation pyrometer and used by the controller to determine how to vary the firing rate in order that the furnace be maintained at a proper temperature level. It is assumed that any departure from this prescribed level will adversely affect the performance of the system in that the slabs will not reach the temperature required for the subsequent rolling operation, or that the steel quality will be impaired through overheating of the surface, or furnace efficiency will be degraded because of excessive heat losses or wear of the refractory lining. Note that if the heat content or the average temperature of the slab is the output variable under consideration, it may have to be determined by inference through a heat transfer model for the slab, using measured values of the external temperature as input.

We comment that the classification of a particular variable may depend on the nature and level of the decision-making process under consideration. For example, while furnace temperature is an output with respect to the temperature control system referred to above, it serves as an input with respect to slab discharge temperature, and it is only implicitly incorporated in the parameters of the capacity model used in scheduling the furnace.

4) State variables: in essence, these are variables associated with the memory characteristics of the plant. In the case of deterministic, dynamic systems, the state vector compacts the relevant past history of the plant, such that, knowing the inputs to the plant over a given time interval, the outputs are determined uniquely over that same period. More generally, the state vector may identify the status of energy or material storages in the system, for example, the number of slabs of each type stored in the slab yard; the current mode of operating units, for instance, the stage in its operating cycle of a BOF

unit; and other factors which are necessary to the identification of the appropriate input-output relationships (models) currently applicable.

Thus, we imply a plant model of the general form

$$y = g(m,z,s) \qquad (1)$$

where y, m, z, s denote vectors of output variables, controlled inputs, disturbance inputs and state variables, respectively. Here $g(\cdot)$ denotes a vector of functional relationships which may be expressed in the form of algebraic functions, integral equations, graphs, tabulated data, or other form appropriate to the application. The variables may be continuous or discrete functions of time; they may be real-valued, integer-valued (for example, quantized data) or Boolean-valued.

The model may be developed theoretically or empirically. In the former case, we invoke known principles and relationships of physics, chemistry, etc., to derive analytical expressions of the form of eq. (1). In the latter case, we employ methods of experimental design, correlation analysis, regression, etc., to develop the desired input/output characterizations. Often we arrive at the desired result through a combination of the two approaches: theoretical analysis yields the form of the relationship and identifies the dominant factors, while regression or correlation techniques are used to evaluate the parameters of the model. An example is provided by the thermal model of a furnace where the laws of radiative heat transfer may establish the structure of the model, but where experimental observations of input-output values provide the basis for determining the "effective" heat transfer coefficient values. This point will be referred to later when we discuss adaptation of the model to changing conditions.

The models used in the integrated control systems are, for the most part, simple linear algebraic equations which take the general form

$$y_i = \sum_{j=1}^{M} a_{ij}m_j + \sum_{j=1}^{Z} b_{ij}z_j$$

$$i = 1,2,\ldots,Y$$

where the a_{ij} and b_{ij} are the (constant) parameters of the model, $m_1,m_2,\ldots,m_M$ denote the controlled inputs, $z_1,z_2,\ldots,z_Z$ are the disturbance inputs, and $y_1,y_2,\ldots,y_Y$ are the outputs under consideration. In more compact vector-matrix notation we have

$$y = Am + Bz$$

where y, m, and z denote vectors and A and B denote matrices (composed of the elements a_{ij} and b_{ij}, respectively) of appropriate dimensions. Note that if the plant may operate in multiple modes or states, there will be a parameter set corresponding to each state which can be stored in the computer data base and recalled as needed.

The linear model may indeed reflect a linear relationship of the plant as, for example, in a material balance model where y represents the composition of a mixture or blend and $m_1, m_2 \ldots$ represent the amounts or flowrates of the various raw materials, with the coefficients (elements of the matrix A) corresponding to the relative concentrations of the components of the input materials. More generally, the linear equation is an approximation to a nonlinear relationship where the variables represent changes from a norm or reference condition. In this case, the coefficients of the equations are sensitivity factors; for example, a_{ij} represents the effect of a unit change in the input m_j on the output y_i.[4] The models described in the previous section for estimating the manufacturing time and production cost for each product type are examples of linear approximations used for a generally complex nonlinear relationship. Such approximations are valid only when the operating conditions remain reasonably close to the established norms or to the conditions under which the coefficients were evaluated.

The algebraic model implies static or steady-state characteristics of the plant. Occasionally a dynamic model is required as when the plant is a batch or time-cycled process and we are interested in its time-varying behavior. The BOF is a case in point and dynamic models based on differential equations (or difference equations in the discrete formulation) are used in some end-point control algorithms. Incidently, the set of initial conditions required for the solution of the differential (difference) equations plays the role of the state vector in such models.

In operations control applications, the models may take the form of logic or Boolean relationships. For example, in the transfer of ingots to soaking pits, the model must describe the availability of cranes and pits, the allowable transfer paths and the sequence of operations (and constraints) necessary to implement the transfer.

---

[4] The coefficient a_{ij} may be determined experimentally by taking the ratio $\Delta y_i/\Delta m_j$, where Δy_i denotes the change in y_i resulting from making a small change in m_j with all other inputs kept constant. If the functional relationship between y and m is known, a_{ij} may also be determined as the partial derivative of y_i with respect to m_j evaluated at the reference condition.

Finally, many of the models employed are simply tabulations of production standards and operating instructions which have been determined on the basis of prior experience and which are stored in the computer data base. When an order is received, the first step in the processing of the order is to determine whether the necessary operating instructions are already on file; if so, they may be recalled from the data base to provide the detailed specifications concerning the chemical composition, metallurgical procedures, mill operations, etc., that are to be implemented--these provide the set-points for the process controllers and the targets for the operations control functions that were described in the preceding section.

Environment

The plant is a subsystem of a large system that we term the environment, that is, all aspects of the external world that interact with the plant and affect its performance with respect to control objectives.

The interactions are of two basic types (see Figure 20 above):

a) inputs to the plant which change its state or affect its behavior; we have already referred to these as disturbance inputs;

b) inputs that affect the objectives or the constraints to be applied by the controller acting on the plant, for example, order specifications.

The characterization of the environment depends on the nature of the control function as well as on what is being considered as the plant. Thus, with respect to control of the BOF, we are concerned with those externalities that affect the grade of steel and the cycle times (for example, scrap composition.) At the production scheduling level, the hot strip mill and blast furnace subsystems are major components of the environment of the steel making subsystem. At the planning level, the environment is dominated by the market as it reflects the demand for different types of products, the costs and availability of raw materials, etc.

In general, the objectives that should be achieved by the plant during future operations are estimated through an analysis of the environment and a forecasting of its future interaction effects (for example, demand). The interactions are typically time-varying functions which, depending on the forecast horizon, can be divided into two parts, a deterministic part that represents an average trend over time, and a stochastic part that represents the unpredicted variations superimposed on this trend. We note that there is a variety of techniques routinely applied in current planning systems for forecasting product demand, economic factors, etc.; these include trend analysis, regression, exponential smoothing algorithms, correlation methods, spectral analysis, etc.

Performance Evaluation

In the design of the decision-making/control system, it is necessary to have defined the criteria for measuring and evaluating plant performance in order that appropriate references or targets for control may be established. At the technological level, we may consider the following objectives:

1) maximizing production efficiency,
2) minimizing operating costs,
3) maximizing the probability of maintaining the plant in a feasible or acceptable operating regime,
4) minimizing the likelihood of failure of the system to perform to standard, for example, failure to satisfy product specifications or environmental constraints.

In practice, the performance criteria used in formulating the decision-making and control algorithms for real-time application are generally simplifications of the above, reflecting the dominant factors entering into the performance measure. Thus, the control associated with a particular unit may act to maximize product yield, throughput rate, or thermal efficiency, or to minimize the consumption of a costly resource, the frequency of quality rejects, or deviations from standards. This point will be referred to again in the discussion of the control hierarchy.

At the economic level, objectives for decision making may include maximizing profit, return on investment, and related indices. Again, the practical criteria will be based generally on approximations and simplifications that are motivated by computational requirements, the form and accuracy of the models used, the nature of the information required, and the reliability of the data available.

We assume that the performance may be expressed explicitly (or perhaps only implicitly) as a function of the system input and output variables, that is,

$$P = \bar{f}(m,y,z,w) \qquad (2)$$

where m,y,z are vectors of controlled input, output, and disturbance variables respectively; w is the vector of external inputs affecting performance, for example, economic factors, product/order specifications, government constraints. Since the system may exhibit significant dynamics (memory effects), the performance measure should represent an integration of plant behavior over a time period that is large with respect to the effective time lag of the system response.[5] Thus, there will be random components of the variables represented in eq. (2) and we imply by the notation $\bar{f}(\cdot)$ that a suitable averaging is carried out over the relevant time horizon.

Controller

If we did not consider the problem of realization, we would ideally like to determine the control or decision-making algorithm so as to achieve an optimal performance, that is, to generate control inputs that satisfy system constraints and result in a maximum of the performance measure P. Formulated analytically,

we have

$$\max_{m \in M} \bar{f}(m,y,z,w) \tag{3}$$

where $M = \left\{ m \mid y = g(m,z,s),\ h(m,y,z,w) \geq 0 \right\}$.

Here M denotes the feasible set of controlled inputs determined by $g(\cdot)$, the set of input-output relationships for the plant, and $h(\cdot)$ denotes the set of inequality constraints applicable to the system. Of course, practical considerations (for example, complexity of the model, cost of implementation) dictate a suboptimal approach to function (3) (which sometimes degenerates to the problem of finding the first feasible solution).

The inequality constraints play a very important role in defining the region of feasible or acceptable plant operation. The constraints may characterize actual technological limits imposed by the equipment or by the nature of the production process, for example, the capacity limit of a machine, the melting temperature of steel. Constraints are also imposed to ensure the safety of operating personnel or of the security of the production means, for example, temperature limits imposed on a furnace in order to avoid too rapid deterioration of the refractory lining. Finally, we impose constraints to ensure that various quality requirements are met, for example, product specifications, effluent pollution standards, etc. An example is the "coffin rule" constraint used in scheduling the rolling operation to ensure that the surface quality of the strip product is not affected by the roll wear.

---

[5] In this case, the arguments of $\bar{f}(\cdot)$ are the complete time functions over the interval of integration. Thus, for example, m in eq. (2) implies $m_{(t_o,t_1)}$ which denotes the time trajectories of the controlled inputs to the system during the interval over which the performance is evaluated.

The result of carrying out the maximization operation of function (3) implies a relationship of the form

$$m = m(y^*, z^*, w) \qquad (4)$$

where y^*, z^* denote vectors consisting of the components of y and z, respectively, that are measured and whose values are used by the controller in generating m.

The contribution of y^* to the control function represents a feedback compensation, that is, a control response to the effects of prior inputs to the plant; the contributions of z^* and w represent feed forward actions, that is, compensations anticipating the effects of current system inputs on subsequent plant performance.

We may further distinguish the control function with respect to the following:

a) programmed mode where the controlled inputs are established in advance based on given demands on the system or requirements of plant performance;

b) compensation mode where the controlled inputs are determined so as to compensate for the effects of disturbances. Their determination may be based on

   1) measurement of the disturbance input and prediction of its ultimate effect on the plant (feed forward action), or

   2) measurement of the effect of the disturbance on the plant outputs directly (feedback action), or, more generally,

   3) a combination of both.

As an example of the programmed mode, the specifications on a given order are translated into sets of operating instructions and constraints that are transmitted to the steel making, rolling, annealing, and other production processes involved in manufacturing the order; these provide the set points, targets, and operation sequences to be implemented by the local controllers. We note that the programmed mode is essentially open loop; however, there are various feedbacks superimposed in practical applications as, for example:

a) The roll settings for the hot strip mill are programmed according to information on slab size, steel grade, and strip gage; adjustment of the settings may be based on the feedback of actual reductions achieved.

b) The operating instructions and standards are updated periodically (or as required) based on production experiences and evaluations of system performance.

Examples of the compensation mode of control include a) variation of the fuel flow to the furnace to maintain the temperature constant by compensating for changes in the thermal load, b) adjusting operating conditions on the BOF cycle based on composition measurements of previous heats c) updating of a production plan according to the results achieved over the preceding planning period.

Note that the realization of eq. (4) may take a variety of forms. Indeed, from the standpoint of plant performance, it is immaterial how the transformations from input information to output decisions/control actions are carried out (that is, whether by algebraic solution of a set of equations, by hill climbing on a fast-time simulation, or simply by table look-up) except as the method might affect the accuracy, the cost, or the speed with which the controller outputs its results. By the same token, the control functions may be performed by man, by machine (computer), or, more generally, by an intersection of both.

The advanced applications of integrated systems control represent an integration of humans (operators, schedulers, planners) with computers serving control and information processing functions. The functions performed by man include those requiring judgments that cannot be standardized, or decision processes that have not been adequately established, or coordinations that involve the integration of a great many factors whose subtleties or nonquantifiable attributes defy computer implementation. The functions performed by computers are essentially those where the tasks are routine and well-defined and where the operating standards are quantified and established. Thus, the main planning and coordination functions are carried out by humans, with computers providing the basic information on which the operator's judgment and decisions are based. The computer is involved in the gathering, processing, and dissemination of data, the distribution of operating instructions and the implementation of controls and operations at the technological level. In addition, as noted earlier, the responsibility for responding to contingency occurrences and special requirements rests generally with the human component of the system.

Control Period

The control function (4) is not carried out continuously but rather at discrete points in time. There are several factors that influence the mean period between successive control actions:

a) the effective time lag for response of the system;

b) the mean time between significant changes in disturbance inputs;

c) the time required for obtaining and processing the data on which the control is based;

d) the time required by the computer (or human decision maker) to determine the necessary control action (this time may be greatly affected by cost considerations)

e) the minimum time interval over which performance evaluation is meaningful.

Thus, there are two alternative policies for initiating control action:

1) Periodic policy: the control action is carried out at uniform time increments independent of whether or not a significant disturbance change has occurred. This is based on an implied assumption that the average cost of controlling with the given period is lower than the cost that would be incurred by testing first to determine if an action should be initiated. Typical examples of a periodic policy are the monthly plan, the weekly schedule, etc.

2) On-demand policy: the control action is carried out in response to an initiating signal or "trigger". Control actions may be initiated by a signal announcing that:

a) a batch operation is ready for a new cycle,

b) a significant disturbance change has occurred since the last control action,

c) a contingency event has occurred requiring an immediate response, or

d) some maximum time interval has elapsed since the last control action.

Examples of an on-demand policy are the reschedule of a mill instigated by a cobble, the revision of a monthly plan caused by an unexpected major equipment breakdown, the start of a new BOF cycle, etc.

In general, we see both types of policy operating in the steel production system. For example, a periodic policy may govern the normal events and operating requirements of a given plant with an on-demand policy superimposed to take care of abnormal events, contingency occurrences, etc.

Information Processor

As noted above, the underlying assumption in the achievement of integrated control is that the controller acts on the basis of (real-time) information concerning the state of the plant, external inputs, etc. We may distinguish several major functions of the information system:

a) the gathering of data and its distribution to points of usage (including sensors, data input devices, transmission links, data banks, etc.);

b) the reduction (interpretation) of raw data into the form required by the decision-making/control function, for example, i) data smoothing, ii) noise filtering, iii) prediction and extrapolation, iv) inference of the value of a variable from indirect measurements, etc.;

c) the monitoring of system status for contingency events to determine whether diagnostic and/or corrective responses are to be initiated;

d) presentation of information for the people interfacing the system, for example, monitoring and control actions by operating personnel, decision making by management, diagnostics for maintenance and corrective actions, record keeping for accounting purposes, etc.;

e) the storage and retrieval of operating instructions, standards, parameter values, and other information required for the functioning of the operating system.

Multilayer Functional Hierarchy

The problems of realization and implementation of an integrated control according to function (3) are generally formidable because of the complexity of the system, the variety of constraints to be satisfied, time-varying behavior, etc. The multilayer, functional hierarchy of Figure 21 provides a rational and systematic procedure for resolving these problems. In effect, the overall problem is replaced by a set of subproblems that are more amenable to resolution than the original problem. Essentially the problem statement of function (3) is modified to

$$\max_{u \varepsilon U} P'(u,x_2,w_2) \tag{5}$$

where

$$U = \left\{ u \middle| G(u,x_2,\alpha_2) = 0, H(u,x_2,w_2) \geq 0 \right\} \;;$$

$$x_2 = \phi(y^*,z^*,\beta) \quad . \tag{6}$$

The resulting decision-making/control algorithm is then of the form

$$u = u(x_2,w_2,\alpha_2) \quad . \tag{7}$$

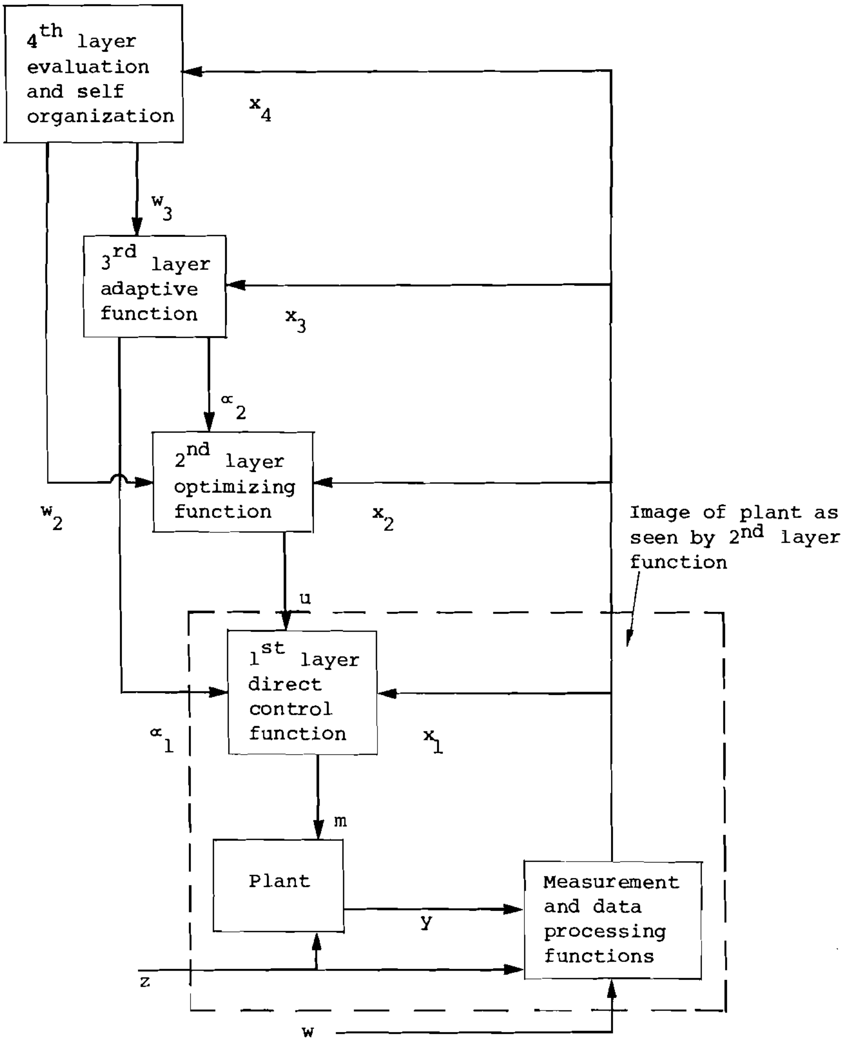


Figure 21. Functional multilayer hierarchy.

The following explanatory remarks are in order:

1) The plant is described by the approximate model

$$G(u,x_2,\alpha_2) = 0 \tag{8}$$

where x_2 is a vector formed by the components of y and z that are relevant to the second-layer (optimizing control) problem. The functions G are simplified approximations to the actual plant relationships (eq. (1)) with the parameter vector α_2 chosen to give a good representation. Note that eq. (8) characterizes the input-output model of the combined system consisting of the plant, direct controllers, and measuring elements as seen by the second layer function (represented by the dotted block in Figure 21). The problem is simplified further by assuming negligible dynamics in the plant model so that G may be represented by static (for example, algebraic) functions, as noted in point 3) directly below. Any state dependent features of the model are assumed to be imbedded in the parameter vector.[6]

2) The vector x_2 characterizes the information from the plant used by the second-layer controller in generating its output u. Eq. (6) represents a data processing function (for example, prediction, averaging, aggregating) based on the measured components of y and z, denoted by y* and z*, respectively. The function ϕ may have an (adjustable) parameter vector β (based, for example, on estimated statistical properties of z), which is adapted to reflect changing conditions. In general, we assume x_2 to be of a lower dimension than the information vector implied in the algorithm (4).

3) The first-layer (direct control) function plays the role of implementing the decisions of the second-layer function, expressed as the vector $u = (u_y, u_m)$, where u_y denotes a vector of set points for y which, through feedback (and feed-forward mechanisms) determines a subset of the components of m; the remaining components of m are determined directly by u_m. This implies the first-layer relationship (see Figure 22)

$$m = m(x_1, u, \alpha) \qquad (9)$$

where x_1 denotes the information used in implementing the direct control function, α_1 is the set of parameters associated with the first-layer algorithms.

---

[6] Of course, where the dynamic or memory aspects of the control problem are significant, then eq. (8) can be formulated as a dynamic model, for example,

$$G(u, x_2, s, \alpha_2) = 0 \qquad (8a)$$

where s denotes the initial state and u and x_2 denote time functions (or sequences) over a finite interval.

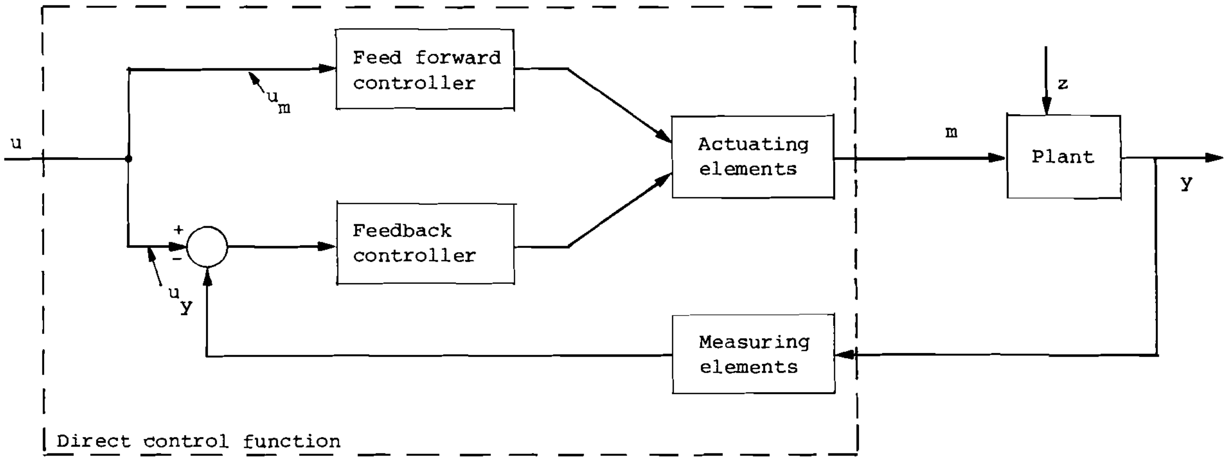


Figure 22. Implementation of the direct control function.

There are two useful consequences of eq. (9):

a) various disturbance inputs may be suppressed with respect to the second-layer problem; for example, by specifying furnace temperature as the decision variable rather than, say heat input rate, we remove the need for explicit consideration (in the optimization) of the many disturbance variables that may effect the thermal equilibrium and heat transfer relationship of the plant; and

b) the dynamic aspects of the control problem may be effectively "absorbed" at the first layer so that static models can be used at the higher layers to good approximation.

4) The vector function H often includes, besides those constraints necessary to ensure safe and feasible operation of the physical system, various artificial constraints whose primary function is to maintain the system within the limited region of operating space for which the approximate model is valid (and hence useful). It is assumed, of course, that the imposition of such constraints will not result in any significant diminishing of the attainable performance. An example of this is the placing of bounds on the maximum rate of change of temperature in the final zone of a reheat furnace so that the assumption of slab homogeneity (on which subsequent slab rolling models are based) is reasonable.

5) The decision algorithm may be based on i) an explicit (mathematical) model, for example, a set of input-output relationships for the subsystem from which the algorithm is derived via an optimization procedure, or ii) an implicit model, for example, a decision (look-up) table based on empirical rules. In either case, the algorithm is based on some simplified, approximate image of the physical system which is valid only in the neighborhood of a given "state" or set of circumstances. As these change with time, it is necessary to update the algorithm, either directly by adjusting some of its parameters, or indirectly via the parameters of the underlying model. The updating is carried out by the third-layer adaptive function in response to current experience with the operating system as conveyed through the information set x_3. This means that we can eliminate from the problem formulation of eq. (5) those factors or disturbance inputs which tend to change infrequently relative to the period of control action (for example, fouling of a heat transfer surface, seasonal variations in cooling water temperature, changes in mill characteristics), since these may be compensated through the adaptive functions.

6) The external (economic) factors contained in w are now inputted via a fourth-layer (evaluation and self-organization) function and are transmitted to the second-layer model via the vector w_2. Changes in w may influence the weighting of terms in P' or some of the bounds imbedded in H. More generally, the evaluation of performance (through the information set x_4) may lead

to modifications in the structure of the control system, for example, in the constraint set U. Finally, we note that contingency events may also lead to changes in the system relationships or the objective function (manifest as changes in U and/or P'), for example, the shift from normal operation of a mill to an emergency mode following a cobble or breakdown.

7) The underlying principles of the multilayer functional hierarchy apply equally well to control of continuous, semicontinuous, and batch processes. In the continuous case, the plant model may be described by algebraic equations (assuming that transient effects may be neglected); in the batch case, differential or difference equations may be required to characterize the plant.[7]

A case in point is a heating furnace. The second layer function may determine trajectories of furnace temperature (as the control input) and slab temperature (as the state vector) so that a specified final temperature of the slab is achieved with minimum fuel consumption. The trajectories may be computed prior to the start of each new batch of slabs, with inputs based on measured initial slab temperature, slab dimensions, estimated thermal coefficients, etc.

The first layer has the problem of implementation. There are a variety of disturbances that cause the actual trajectories to deviate from the computed optimal (reference) paths (for example, changes in heat transfer properties from those predicted, errors in the model used, etc.). One form that the first-layer control may take (to compensate for the disturbances) is to minimize a weighted mean square deviation of the actual trajectories from their reference paths, applying optimal control theory (linear model, quadratic criterion). It is clear, in this application, that the third-layer adaptive function may update the parameters of the (nonlinear) second-layer model, as well as perhaps the weighting of coefficients of the quadratic criterion used at the first layer (assuming the coefficients for the linearized model are evaluated at the second layer along with the reference trajectories). The fourth-layer functions will be concerned with the same overall considerations as discussed previously.

8) There is a large variety of ancillary tasks normally carried out in conjunction with the control functions identified in the multilayer hierarchy. These might be looked upon as "enabling" functions that are deemed necessary or useful to the pursuit of the overall system goals. Indeed, the provision for

---

[7] This, of course, requires a modification of the relationships implied by eq. (5) to reflect the dynamics of the change of state. This is a straightforward extension of the static formulation presented here and will not be further elaborated in this discussion.

such tasks is often a very significant factor in determining hardware and software requirements in computer control applications. Among such ancillary functions we include:

a) data gathering (filtering, smoothing, data reduction);

b) record keeping (for plant operator, production control, management information, accounting, etc.);

c) inventory maintenance (for example, keeping track of goods in process);

d) sequencing of operations (for example, startup/shutdown operations, slab transfer operations, BOF cycling operations).

The essential feature of these functions is that they are routine, repetitive and open-loop; hence, they can be handled by stored programs and fixed hardware. Considerations of decision making and control may come into the picture at the higher layers, however, with respect to modifying the procedures, operating sequences, etc., based on evaluation of performance or in response to contingency occurrences.

Multilevel Control Hierarchy

We consider again the optimization problem (5) reformulated[8] for convenience as follows:

$$\max_{u \in U(z)} f(u,y,z) \tag{10}$$

where

$$U(z) = \left\{ u \mid y = g(u,z),\ h(u,y,z) \geq 0 \right\}$$

where f is the measure of overall performance (objective function); u is the vector of decision variables (controller outputs); y is the vector of plant outputs; z is the vector of disturbance inputs; U(z) denotes the feasibility set (conditional on z); g and h denote vectors of equality and inequality constraints, respectively.

We assume that problem (10) has a solution, $u^o(z)$; however, despite the simplifications introduced into the model via the multilayer approach, the solution is still too difficult or too

---

[8] Besides slight changes in notation, we have suppressed the dependence of the functions on w and α (that is, we have assumed these are fixed over the time horizon of the optimization problem).

costly to obtain directly in a form suitable for on-line implementation (limiting factors may include excessive computation time, inadequate storage capacity of the available computer, complexity of the program with respect to maintenance and reliability, etc.). The multilevel approach, where applicable, provides a means of circumventing the difficulty by decomposing the overall problem into a number of simpler and more easily solved subproblems. Thus, in application to the problem, we assume that the functions are separable in the sense that they can be decomposed into N subproblems as follows:

i^{th} subproblem:

$$\max_{u_i \varepsilon U_i} \quad f_i(u_i,y_i,q_i,z_i) \qquad i = 1,2,\ldots,N$$

where

$$U_i = \left\{u_i | y_i = g_i(u_i,q_i,z_i),\ h_i(u_i,q_i,z_i) \geq 0\right\} \quad ,(11)$$

subject to the interaction constraints,

$$q_i = \sum_{j=1}^{N} T_{ij}y_j \qquad i = 1,2,\ldots,N \quad . \quad (12)$$

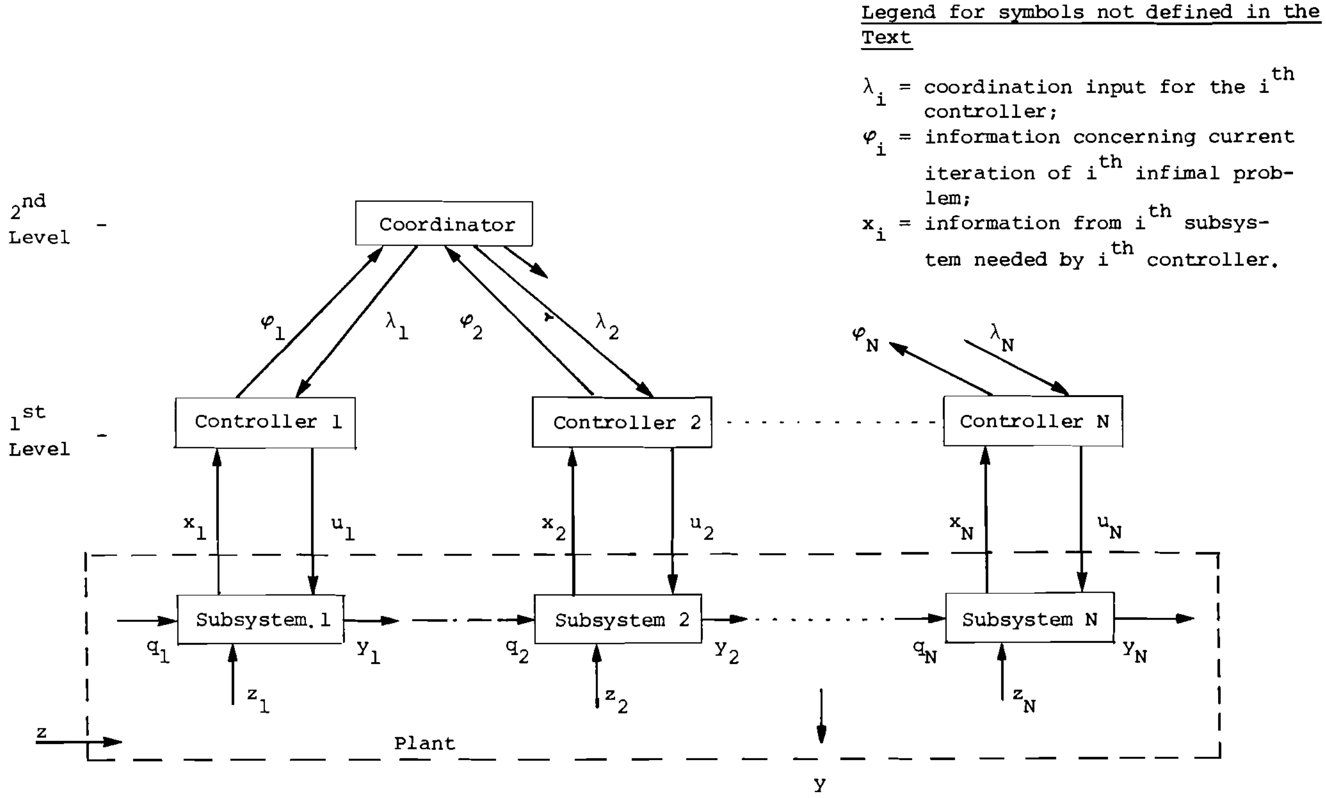
The variables are identified with reference to Figure 23. Except for the q_i, the notation follows that of eq. (10) with the modification that the subscript i particularizes the vectors and functions to the i^{th} subsystem.[9] The vector q_i denotes the inputs to subsystem i which are the result of its interactions with other subsystems. These interaction inputs may be expressed in the form of eq. (12) where the T_{ij} are matrices of zeros and ones which couple the components of q_i with the appropriate components of y_j, $j \neq i$. It is assumed that

$$f(u,y,z) = \sum_{i=1}^{N} f_i(u_i,y_i,q_i,z_i) \qquad (13)$$

when q_i is given by eq. (12), and that a solution satisfying the constraint sets U_i, $i = 1,2,\ldots,N$, simultaneous with the

---

[9] Note that whereas the u_i,y_i,q_i are assumed to be disjoint subsets of u, y, and q, respectively, it is not necessary to impose such a restriction on the z_i; that is, a disturbance input may affect one or more subsystems.



Legend for symbols not defined in the Text

λ_i = coordination input for the i^{th} controller;

φ_i = information concerning current iteration of i^{th} infimal problem;

x_i = information from i^{th} subsystem needed by i^{th} controller.

Figure 23. Multilevel hierarchical structure.

interaction constraints (12) will also satisfy the overall constraint set U (in eq. (10)).

In the multilevel hierarchy, the subsystem problems (11) are solved at the first level of control. These solutions have no meaning, however, unless the interaction constraints (12) are simultaneously satisfied. This is the coordination problem that is solved at the second level of the hierarchy.

A variety of coordination schemes have been described in the literature,[10] for example, price adjustment coordination (interaction balance), primal coordination (interaction prediction), penalty function methods, etc. These are all similar in the sense that they serve to motivate an iterative procedure for solution of an optimization problem wherein a set of local subproblems are solved at the first level in terms of a set of parameters specified by the second level. The methods may differ, however, in their applicability to a specific problem, in the computation requirements, convergence speed, sensitivity to model error, incorporation on-line, and other considerations.

The price adjustment method is based on the Lagrangian formulation of the problem. Thus, the Lagrangian function based on eqs. (12) and (13) is given by

$$L = \sum_{i=1}^{N} \left[f_i(u_i,y_i,q_i,z_i) + \lambda_i^T(q_i - \sum_{j=1}^{N} T_{ij}y_j) \right] \qquad (14)$$

where λ_i, $i = 1,2,\ldots; N$ are vectors of Lagrangian multipliers.

Defining the Lagrangian associated with the i^{th} subsystem

$$L_i = f_i(u_i,y_i,q_i,z_i) + \lambda_i^T q_i - n_i^T y_i \qquad (15)$$

where

$$n_i^T = \sum_{j=1}^{N} \lambda_j^T T_{ji}$$

we have

$$L = \sum_{i=1}^{N} L_i \qquad (16)$$

---

[10] A list of references may be found at the end of this section. Refer in particular, to Mesarovic et al; Himmelblau and Wismer might also be cited here.

and, hence, we may express the first-level problems as

$$\max_{u_i, q_i} L_i(u_i, y_i, q_i, z_i, \lambda), \qquad i = 1,2,\ldots,N$$

subject to

$$y_i = g_i(u_i, q_i, z_i), \quad h_i(u_i, q_i, z_i) \geq 0 \tag{17}$$

where

$$\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_N).$$

The solution of the N first-level problems for given values of z (based on current measurements on the system) and λ (given by the second-level coordinator) yields u_i^*, q_i^*, y_i^* for

$i = i,2,\ldots,N$. We can use these values at the second level

$$\min_{\lambda \varepsilon D} \sum_{i=1}^{N} L_i(u_i^*, y_i^*, q_i^*, z_i, \lambda) \tag{18}$$

where D is the permissable set of λ values for which solutions to the first-level problems exist. The resulting λ is then fed back to the first-level controllers and the procedure is iterated until convergence to a constant (non-zero) λ value is attained. Achievement of this result implies that the interaction constraints (12) are satisfied and that an optimum to the overall problem has been obtained.[11]

In the primal coordination method, the interaction variables are set by the second-level controller so that the first-level problems reduce to

$$\max_{u_i \varepsilon U_i} f_i(u_i, y_i, q_i^*, z_i), \qquad i = 1,2,\ldots,N$$

where

$$U_i = \left\{ u_i \middle| y_i = g_i(u_i, q_i^*, z_i), h_i(u_i, q_i^*, z_i) \geq 0, \right.$$

$$\left. q_i^* = \sum_{j=1}^{N} T_{ij} y_j \right\} \tag{19}$$

---

[11] Actually, some further conditions may be necessary; see Mesarovic et al.

with $\{q_i^*\}$ given by the second-level coordinator. The first-level solutions are denoted by the set $\{u_i^*\}$ and are transmitted to the second level which solves the coordination problem,

$$\max_{q \varepsilon Q} \sum_{i=1}^{N} f_i(u_i^*, y_i, q_i, z_i)$$

where

$$Q = \left\{ q = (q_1, \ldots, q_N) \;\middle|\; q_i = \sum_{j=1}^{N} T_{ij} g_j(u_i^*, q_i, z_i) \;, \quad h_i(u_i^*, q_i, z_i) \geq 0 \right\} . \tag{20}$$

The procedure is iterated until convergence is reached.

On-Line Control Application

As far as the plant is concerned, it is only the final result of the iterative process that is important, that is, the functional relationship $u^o(z)$ that is established. Thus, the entire multilevel structure is internal to the computational block generating the optimum control. However, in the on-line application, the computation depends on the current value of z and this changes with time. Thus, much of the advantage of decomposition may be lost if the iterative process of coordination has to be repeated with every change in disturbance level.

If the system is decomposed along lines of weak interaction and if the coordination scheme is selected so that intermediate results are always plant feasible, then the multilevel structure provides the basis for a decentralized control wherein:

a) The first-level controllers compensate for local effects of the disturbances, for example, maintain local performance close to the optimum while ensuring that local constraints are not violated.

b) The second-level controller modifies the criteria and/or the constraints for the first-level controllers in response to changing requirements on the system so that actions of the local controllers are consistent with the overall objectives of the system.

c) The second-level controller compensates for the mean effects of variations in the interaction variables.

The decentralized scheme provides the following advantages:

a) a reduction in the total computational effort because of less frequent second-level action;

b) a reduction in data transmission requirements because i) most of the control tasks are handled locally, ii) much of the information required at the second level consists of averaged, aggregated data, and iii) the upper level action takes place at lower frequency;

c) a reduction of development costs for the system by virtue of the fact that the models, control algorithms, and computer software can be developed in a step-by-step, semi-independent fashion. By the same token, the problems of system maintenance, modifying and debugging programs, etc., are considerably simplified;

d) there is increased system reliability because i) a computer malfunction at the first level need only affect the local subsystem, and ii) the system can operate in a suboptimal but feasible mode for some time in the event of a failure of the second-level computer.

Weak interaction linkages are readily motivated in industrial systems because the plants are composed typically of interconnections of semi-independent processing units. The interaction may be further weakened by design:

a) The introduction of storage units between subsystems serves to buffer one from the other. This is common practice in the steel industry as evidenced by the presence of slab yards, coil yards, etc.

b) Key interaction variables may be independently controlled to reduce their variations. Examples here include ore blending to minimize the variability of ore feed to the blast furnace, the grouping of slabs scheduled for the reheat furnace to minimize size variations from slab to slab (which affects the time required for heating a slab to its desired temperature).

c) The local controllers may be designed to reduce the sensitivities of select output variables to local disturbances, thereby maintaining interaction effects relatively invarient. For example, temperature control of the slab furnace reduces the variation of slab temperatures from target values and hence decouples various furnace disturbances from the downstream rolling operation.

We remark that the measures taken to decouple the subsystems are not without cost (both capital and operating) and that there are economic trade-offs to be exploited via the multilevel hierarchy, for example, increasing the degrees of freedom by relaxing the coupling constraints--at the expense of more frequent coordination at the second level. As illustration, reference has already been made in the previous chapter to some of the trade-off considerations associated with storage capacity. Increased storage tends to reduce the coupling between successive production units at the expense, however, of increased costs associated with in-process inventory, material tracking and handling, and product deterioration.

Consider the primal coordination method and assume that the first-level controllers operate with period T_1 and the second-level controller operates with period T_2, $T_2 > T_1$. Say the integrated problem (19) and (20) is solved at time kT_2 based on a predicted mean value of z appropriate for the interval $[kT_2, (k + 1)T_2]$. This yields a solution for the interaction variables denoted by $q_i(kT_2)$ $i = 1, 2, \ldots, N$. The first-level controllers then solve eq. (19) conditional on $q_i = q_i(kT_2)$, until the time $(k + 1)T_2$ when the integrated problem is again solved and the values of q_i are updated.

We note that there is a loss of some degrees of freedom in the above procedure since, in effect, a subset of the control vector u must be assigned the task of maintaining the interaction variables at the values specified by the coordinator. This leads to a degradation of performance relative to what would be attained if the coordination were carried out every time first-level action was required. Since u_i is determined by the i^{th} first-level controller according to eq. (19), the (suboptimal) performance value at some time t within the interval $[kT_2, (k + 1)T_2]$ will depend on z(t) and on $q(kT_2)$ as specified by the second-level controller. Denoting this performance value by $f^*(t; kT_2)$ and letting q(t) represent the value of the interaction vector that would be determined by the second-level controller if it acted again at time t, we have as an approximation to the performance degradation, the expression

$$J(T_2) = \frac{1}{T_2} \int_{kT_2}^{(k+1)T_2} E\left\{ \frac{\partial f^*(t; kT_2)}{\partial q} [q(t) - q(kT_2)] \right\} dt \tag{21}$$

where E denotes expectation with respect to the distribution on z.

Note that the degradation depends on the period T_2 which may be determined so that the average degradation is consistent with the incremental cost of carrying out the second-level control action. We note further that there is usually some flexibility in the choice of interaction variables, that is, variables to be updated by the second-level controller. Thus, by defining the subsystem problems according to weak interaction linkages, we tend to increase the allowable period T_2 for which the degradation is within acceptable limits.

An aspect of the multilevel control application that has particular relevance to industrial systems control is the problem of allocation, by the second-level coordinator, of a finite resource among the first-level units, for example, allocation of investment capital among different works, allocation of steel to the needs of different mills in the works, etc. In this case, the constraint set for the i^{th} subsystem may be modified to incorporate the inequality.

$$h_i(u_i,q_i,z_i) \leq \beta_i \tag{22}$$

where $h_i(\cdot)$ represents the i^{th} subsystem's requirement for the given resource and β_i is the local resource allocation (or target) determined by the coordinator according to overall objectives and constraints. We remark that the allocation problem has been studied extensively and a number of programming techniques (linear programming, integer programming) have been applied. Again, the decomposition approach provides benefits resulting from simplified subsystem problems, reduced frequency of computation of the integrated problem, reduced sensitivity of the overall performance to uncertainties in the system inputs, etc.

Applications

There is a variety of applications of the multilevel concept in steel making; indeed, industrial systems have tended to evolve along well-defined hierarchical structures based on the characteristics of the technological processes involved and on the management organization. For example, in the steel industry, we have a hierarchy of decision making and control defined according to the following levels:[12]

- company level,
- product division level,

---

[12] This structure is fairly typical although there are some variations in practice among countries and companies.

- works level,
- mill level,
- production unit level,
- machine level,
- operations/process control level.

In general, each level serves as coordinator to resolve conflicting needs and goals among the infimal units at the level below. The coordination methods used in practice tend to be informal and ad hoc; it is expected that, as the degree of computerization and integration of the system increases, the need for more formal structuring and definition of tasks will be felt and the developments of multilevel theory will play an increasingly important role.

Two examples of multilevel coordination are cited:

1) The temperature of slabs leaving the reheat furnace for the hot strip mill may serve as a coordination variable with respect to the objective of maximizing operating efficiency of the furnace rolling mill subsystem. Thus, the slab temperature affects the maximum throughput rate of the furnace as well as the fuel consumption. On the other hand, the slab temperature affects the power required in the rolling and also the finishing temperature of the strip (and indirectly, the production rate of the mill). There is an optimum slab temperature with respect to overall performance of the mill (depending on slab dimensions, strip specifications, grade of steel, etc.). Thus, the determination of this temperature is a task for the second-level controller that is coordinating the first-level controllers applied to the furnace and rolling mill subsystems, respectively. The first-level controllers act to maintain optimum performance of their respective subsystems conditioned on the specified slab temperature constraint.

2) As was pointed out in a previous Section, the wear of the working and backup rolls of the hot strip mill impose constraints on the allowable sequence of strip widths and thicknesses that may be rolled between successive roll changes. Deviations from this sequence result in either degraded strip surface quality or reduced mill production, both undesirable with respect to mill performance. However, in order to follow the prescribed sequence (and still meet delivery commitments, etc.), slabs of different sizes and grades are often required. However, the BOF scheduler wants to minimize the number of grade changes because of the increased likelihood of off-standard heats during the transition from one grade to another. Similarly, there is a significant setup cost associated with changing slab dimensions on the continuous casting machine, hence, the slabbing department wants to minimize the frequency of slab changes. An alternative is to

provide more storage of slabs in the slab yard but, as we have already stated, this may increase slab yard costs. Thus, we have a role for a higher level production scheduler that reconciles the conflicting (local) objectives of these interacting production units to satisfy overall objectives and constraints.

3) When the demand for steel exceeds the total capacities of the blast furnaces, or of the steel making facilities, it is necessary to allocate the BOF heats among the various product types and mills (strip, plate, sections, etc.). The supremal unit determines an allocation which attempts to maximize overall performance (say company profit); the infimal units operate to minimize costs subject to constraints of order due dates, specifications, etc. Feedback of infimal performances, constraint violations, etc., provide the supremal unit with inputs on the basis of which the allocation rule may be improved.

We make two final remarks:

a) The multilevel structure extends in an obvious fashion to a hierarchy of three or more levels with each supremal unit coordinating the actions of a group of infimal units according to the same principles as described above. Figure 24 illustrates a four level structure with C_{ij} denoting the j^{th} controller at the i^{th} level, and P_i representing the i^{th} plant subsystem. With respect to the fourth level controller C_{41}, the structure of infimal units may be collapsed to the equivalent single level structure comprised of units C'_{31} and C'_{32} as "seen" by the supremal unit.

b) The multilevel control hierarchy is particularly compatible with the trend to distributed computer control structures based on minicomputers and microprocessors performing dedicated tasks which are coordinated through the systems integration. This will be discussed further in the context of a particular system.

Temporal Control Hierarchy

As we remarked in the discussion on the multilevel control hierarchy, the structure induces an ordering with respect to time scale; specifically, the mean period of control action tends to increase as we proceed from a lower to a higher level of the hierarchy. In addition, any controller within the multilevel structure may itself represent a series of control tasks that tend to be carried out with different frequencies or time priorities. This motivates the concept of a temporal control hierarchy wherein a control or decision-making problem is partitioned into subproblems based on the different time scales relevant to the associated action functions. These time scales reflect such factors as:

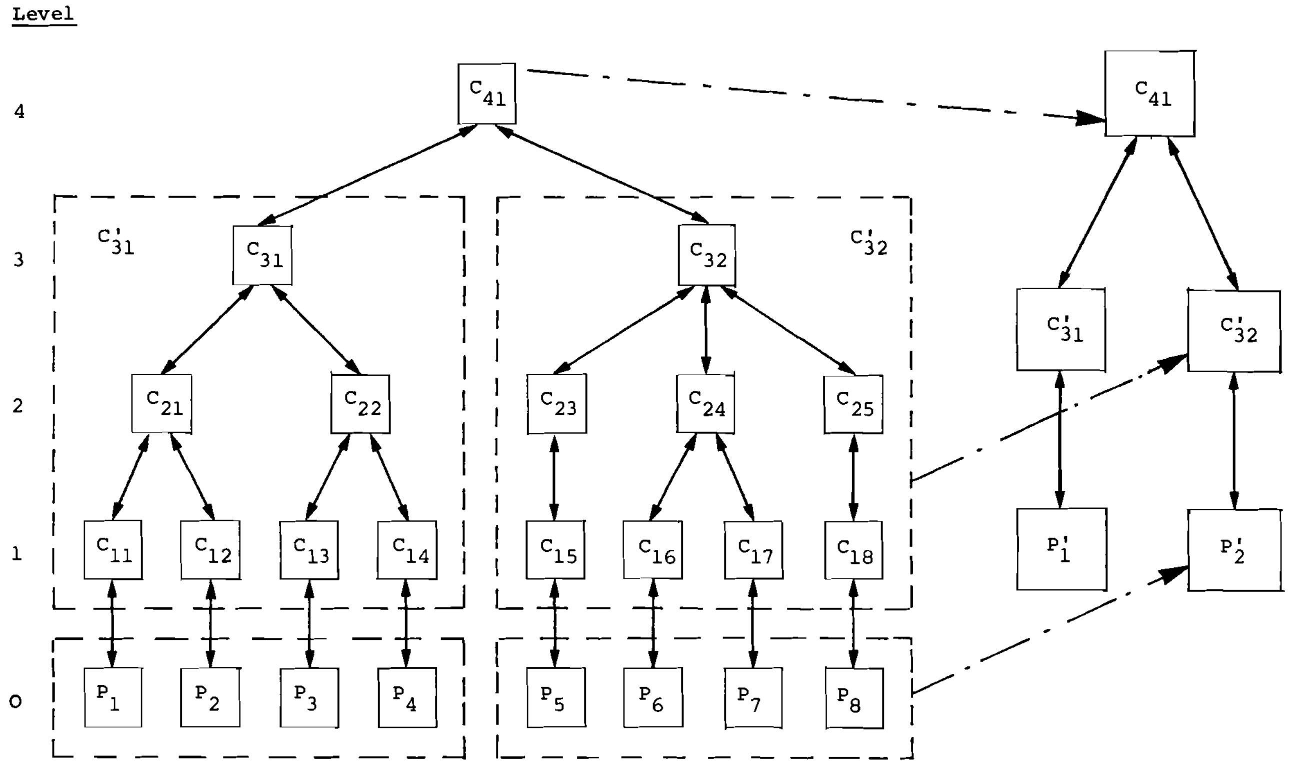


Figure 24. Collapse of four level hierarchy to equivalent two level structure.

1) the minimum time period required for obtaining the necessary information; for example, the determination of statistical parameters require sufficiently long data records to be meaningful; the composition of a heat is available only after completion of the steel making cycle;

2) the minimum time period for the system to respond to prior actions, for example, the dominant time constant for a continuous process, the construction time for a new plant or equipment installation;

3) time-varying characteristics of the disturbance inputs as displayed by bandwidth properties, mean time between discrete changes in input conditions, etc., (for example, seasonal and diurnal changes in cooling water temperature, mean time between receipt of an order requiring special processing);

4) minimum time horizon for which the solution to the control problem has meaning;

5) trade-off considerations relating the benefit of control action versus its cost.

An example of a set of control functions distinguished by their temporal attributes is provided by the hot strip mill. As described previously the rolls are replaced periodically because of wear; the backup rolls are changed on a cycle of eight to ten days and the working rolls on a six to eight hour cycle. With each roll change, there is set in motion a sequence of events by which the mill goes from its normal operating mode to a roll change mode and back again, with the attendant shutdown and start-up procedures, etc.; the roll change also affects the sequencing of slabs over the subsequent operating period. The advent of each new order, involving perhaps a great many slabs, requires new mill instructions and setups. Each individual slab in turn initiates a series of actions relating to roll settings, speeds, etc. Finally, various feedback mechanisms apply in almost continuous action to maintain strip tension, thickness, and temperature at predetermined values. Thus, there is a broad spectrum of control and decision-making activities ranging in time scale from seconds to weeks and these activities interact in a special way because of the temporal relationships.

A second example, of particular relevance to our discussion of the temporal control hierarchy, is provided by the planning and scheduling operations. Thus, common to much of the steel industry is an articulation of planning functions with progressively shorter time horizons, for example, ten years, five years, annual, monthly, weekly, daily, shift, hourly (refer to the discussions on planning and scheduling in previous sections.) Besides the obvious ordering with respect to time scale, there are related characteristics that have to do with the form of the model, the degree of uncertainty involved in the decision making, the level of aggregration, the information flow requirements, etc. These are discussed further below.

Figure 25 shows the basic structure of the temporal control hierarchy. It is assumed that the control problem is partitioned to form an L layer hierarchy where C^k, k^{th} layer control function, generates a decision or control action every T^k units of time (on average), with[13]

$$T^{k+1} > T^k \qquad k = 1,2,\ldots,L - 1 \quad .$$

Associated with the k^{th} layer control function are the following inputs and outputs:

x^k - information set describing the state of the plant and environmental factors relevant to the k^{th} layer decision process.

u^{k+1} - decisions of the $(k + 1)^{th}$ layer controller that exert priority over the k^{th} layer control process; in particular, u^{k+1} provides targets and/or constraints for the k^{th} layer problem such that the actions of C^k are consistent with the goals set for the overall problem.

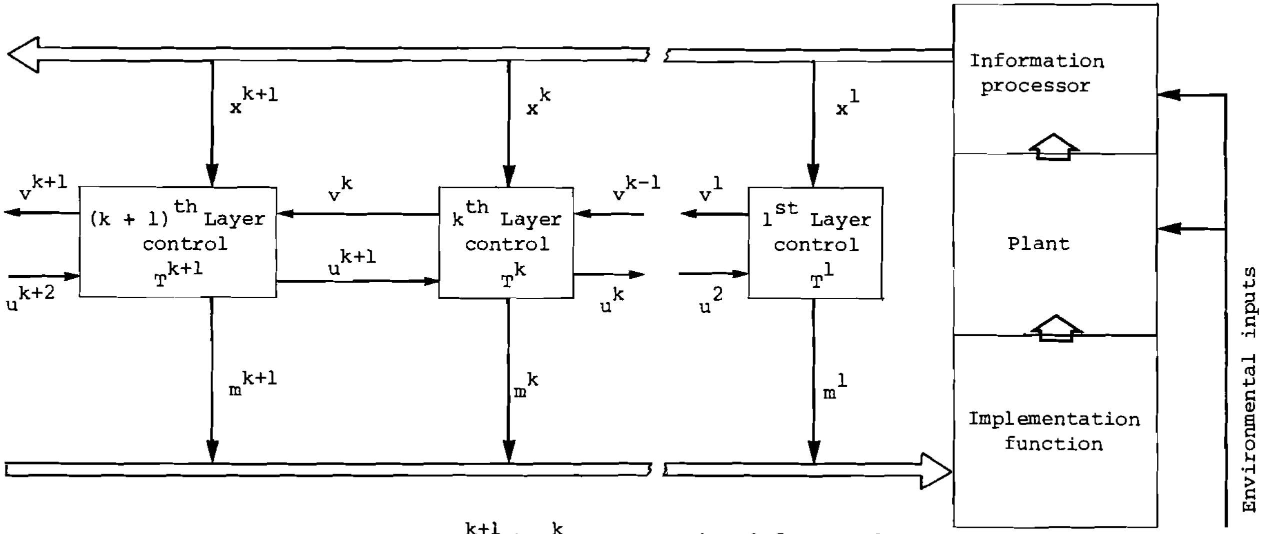
v^{k-1} - information from the infimal unit C^{k-1} relevant to the k^{th} layer function, for example, feedback of the results of prior actions of C^k.

m^k - actions of the k^{th} layer controller applied directly to the plant; tasks to be carried out in conjunction with the control output u^k.

Let t^k denote the most recent time, prior to some specified time t, at which a k^{th} layer control action has occurred. We assume that a k^{th} layer action automatically triggers actions at all lower layers in order to ensure consistency with the notion

---

[13] In the case of a periodic control policy, T^k is predetermined and constant. For an on-demand policy, T^k denotes the mean period of k^{th} layer action.



$$T^{k+1} > T^k \quad , \qquad k = 1,2,\ldots,L-1$$

Figure 25. Temporal control hierarchy.

that C^k exerts priority over C^{k-1}. Accordingly, we have the ordering,

$$t^{k+1} \leq t^k \leq t < t^k + T^k \leq t^{k+1} + T^{k+1} \qquad (23)$$

$$k = 1,2,\ldots,L-1 \quad .$$

At time t^k, the k^{th} layer controller generates the output $u^k(t^k)$ based on input information currently available. Thus,

$$u^k(t^k) = f^k[u^{k+1}(t^{k+1}), x^k(t^k), v^{k-1}(t^k)] \quad . \qquad (24)$$

The control u^k is assumed to remain fixed over the time interval $(t^k, t^k + T^k)$ at the value[14] determined at time t^k, that is,

$$u^k(t) = u^k(t^k), \qquad t^k \leq t < t^k + T^k \quad . \qquad (25)$$

Note that $u^k(t^k)$ depends on $u^{k+1}(t^{k+1})$ in eq. (24) by virtue of conditions (25) and (23).

In a similar manner, the temporal structure implies the relationships,

$$v^k(t^k) = g^k[x^k(t^k), v^{k-1}(t^k)] \qquad (26)$$

$$m^k(t) = h^k[u^k(t^k)], \; t\varepsilon[t^k, t^k + T^k] \quad . \qquad (27)$$

We assume further that the information set $x^k(t^k)$ is obtained by measurement of various plant inputs and outputs that are important to the k^{th} layer action (and are available); in particular,

$$x^k(t^k) = \theta^k[\bar{y}^k(t^k), \bar{z}^{*k}(t^k)] \qquad (28)$$

---

[14] Note that eq. (25) implies that $u^k(t)$ is held constant over the control period T^k. This is not a necessary constraint, however, and $u^k(t)$ can represent a time varying function. In this case, it is assumed that the trajectory $u^k(t^k, t^k + T^k)$ is determined at time t^k according to an algorithm of the form of eq. (24).

where

$\bar{y}^k(t^k)$ denotes the subset of plant outputs relevant to C^k and averaged over the interval $[t^k - T^k, t^k]$; $\bar{z}^{*k}(t^k)$ denotes the subset of external inputs that are relevant to C^k and measured; these too are assumed averaged over $[t^k - T^k, t^k]$.

Since y^k is functionally related to the inputs m^k and z^k via the plant relationships, we have also

$$x^k(t^k) = \phi^k[m^k_{(t^k - T^k, t^k)}, z^k_{(t^k - T^k, t^k)}] \qquad (29)$$

where

z^k denotes the subset of environmental inputs to the plant that are significant in their effect on the k^{th} layer decision process.

Making use of equations (23) through (29), we may show the following concatenated results for the hierarchy, where t lies within the interval defined by eq. (23):

$$u^k(t) = F^k[u^{k+1}(t^{k+1}), X^k(t^k)] \qquad (30)$$

$$v^k(t^k) = G^k[X^k(t^k)] \qquad (31)$$

$$m^k(t) = H^k[u^{k+1}(t^{k+1}), X^k(t^k)] \qquad (32)$$

$$x^k(t^k) = \Phi^k[u^{k+1}(t^{k+1}), Z^k(t^k)] \qquad (33)$$

where X^k and Z^k are vectors defined as follows:

$$X^k(t^k) = \left\{x^k(t^k),\ x^{k-1}(t^k), \ldots, x^1(t^k)\right\} \qquad (34)$$

$$Z^k(t^k) = \left\{z^k_{(t^k - T^k, t^k)},\ z^{k-1}_{(t^k - T^{k-1}, t^k)}\ , \ldots,\ z^1_{(t^k - T^1, t^k)}\right\} \qquad (35)$$

The above relationships represent the situation depicted in Figure 26 where the control functions $C^1, C^2, \ldots, C^{k-1}$ have been collapsed into the plant block and where the feedback interrelationships of C^k with the plant system is put into evidence. The external inputs to the system (disturbances, order inputs, etc.), represented by z, are partitioned into subsets $z^1, z^2, \ldots, z^L$, where the i^{th} subset z^i is associated with the control period T^i, $i = 1,2,\ldots,L$. Thus, with respect to the k^{th} layer controller, C^k, generating a control action at time t^k:

v^{k-1} characterizes the residual effects of z^i over the interval $(t^k - T^i, t^k)$, $i = 1,2,\ldots,k - 1$;

x^k characterizes the effect of z^k over the interval $(t^k - T^k, t^k)$;

u^{k+1} characterizes the residual effects of z^i over the interval $(t^k - T^i, t^k)$, $i = k + 1, k + 2, \ldots, L$.

We note that the effects of z^i on C^k for $i < k$ are filtered through the corrective actions of controllers $C^1, C^2, \ldots, C^{k-1}$. Similarly, for $i > k$, the effects of z^i on C^k are modified through the actions of $C^{k+1}, \ldots, C^L$.

The k^{th} layer control action is determined with reference to a decision horizon τ^k where, in general,[15] $T^k \leq \tau^k$. When $T^k = \tau^k$, we have the standard formulation of the stationary horizon problem. When $\tau^k > T^k$ and, more particularly, when $\tau^k = rT^k$, where r is an integer greater than one, then the problem is of the moving horizon type. Viewed as a control problem, τ^k is irrelevant (except as it affects the optimizing procedure), and T^k is the significant parameter. Thus, every T^k units of time the controls are updated based on the current information set.

---

[15] In the case of a static (non-dynamic) system, we assume $\tau^k = T^k$ since this is the interval over which the disturbance inputs are extrapolated (for example, as step or ramp changes).

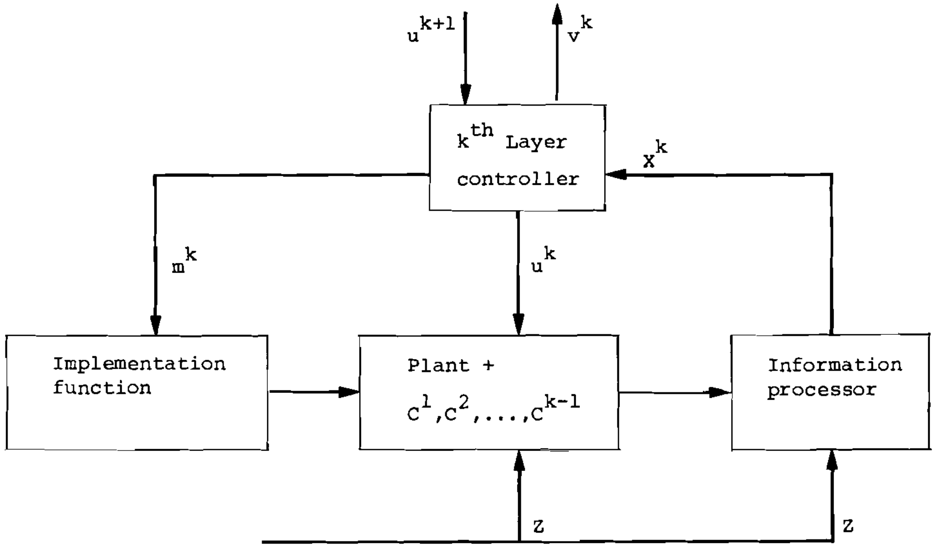


Figure 26. Interaction of k^{th} layer controller with augmented plant system.

We comment that the k^{th} layer controller may require many detailed and complex iterations in generating u^k; further, the information set x^k, on the basis on which u^k is determined, may come from a variety of sources where data may be collected over periods of time. We assume, however, that the results of control action or decision making is inputted to the system at specific points in time with period T^k. Thus, the iterations are internal to the decision-making block and have no effect on the output except for the introduction of a delay between the information input and the control output. This delay may also be influenced by the data collection process.

The decomposition according to the above considerations is only approximated in practice. There are various factors affecting the decomposition that may be selected (or modified) in the design process. These include:

a) the choice of time scales, that is, the selection of control periods $T^1, T^2, \ldots, T^L$;

b) the classification of external inputs into the subsets $z^1, z^2, \ldots z^L$; the identification of z^k then determines the role to be played by C^k (in compensating for the effects of z^k);

c) the choice of measured variables and associated data processing functions (averaging, aggregating, etc.) which constitute the information set x^k.

There is a variety of analytical and experimental tools that might be used in determining reasonable choices for the above factors, for example, correlation methods, sensitivity analysis, etc. Thus, a spectral analysis of the disturbance inputs may suggest an initial basis for their classification. For example, if $T_o = 2\pi/\omega_o$, where ω_o is the lowest frequency (in radians per unit time) at which a particular input exhibits significant energy content (in terms of its power density spectrum), then when

$T^k > T_o$: we may consider the effects of variations of the input to average out over T^k and hence C^k needs to use only the mean or expected value of the input.

$T^k \sim T_o$: the disturbance appears as a nonstationary input with respect to C^k and hence C^k should attempt to apply compensating action.

$T^k << T_o$: the disturbance is essentially constant over the period T^k and it can be absorbed within the model as a parameter (which may be updated by an adaptive function at a higher layer).

An important consequence of the temporal hierarchy is the simplification of the models used in generating the control functions. Thus, with respect to the k^{th} layer control function, 1) the model excludes variables whose effects tend to average out over T^k, 2) variables that are relatively constant over the decision horizon are parameterized, 3) remaining variables are aggregated, and 4) the period T^k is selected (out of a set of feasible control periods) so that the mean deviation of the results described by the model from those actually achieved by the plant is acceptably small. Alternatively, we may require that the degradation of performance of the system attributed to the model simplifications at the k^{th} layer be within a given tolerance.

We may again use the slab heating furnace as an example. Here we distinguish four layers of control action according to relative time scale:

Layer 1: process control functions vary the fuel flow rates into the furnace in order to maintain the furnace temperature along a specified trajectory.

Layer 2: the optimizing control model determines the desired temperature trajectory based on load and mean operating conditions; minor disturbances and transients are neglected.

Layer 3: the scheduling model calculated the cycle time as a function of the charge, assuming a mean value for the furnace temperature.

Layer 4: the planning model makes use of the mean cycle time as a standard in determining furnace production capacity.

Note that each of the models may be updated with changes in the underlying assumptions.

We have already referred to the planning and scheduling process as a special application of the temporal hierarchy. The essence of the problem is that the overall decision horizon is very long, the system is very complex with a large number of diverse inputs, and we have only very limited information concerning the inputs. The temporal control hierarchy formalizes a rational basis for mitigating these difficulties through aggregated models and through feedbacks which tend to reduce the effects of uncertainties and model approximations.

We consider, in this application, the following special characteristics:

1) The decision horizon is an integral multiple of the control period,

$$\tau^k = rT^k, \qquad r > 1 \quad .$$

2) The k^{th} layer control period equals the decision horizon for the $(k - 1)$ layer,

$$T^k = \tau^{k-1} \quad .$$

3) The k^{th} layer control problem, P^k, is solved repetitively every T^k time units. The solution at time nT^k is associated with the interval $[nT^k, nT^k + \tau^k]$; however, $u^k(nT^k)$ need reflect only the initial segment of the solution function, that is, the output segment for the interval $[nT^k, (n + 1)T^k]$. This constitutes the allocation or target for the $(k - 1)^{th}$ layer control problem.

4) The control output $u^k(nT^k)$ is determined on the basis of (see eq. (23)):

   a) the target or allocation u^{k+1} set by the supremal unit;

   b) the current estimate of the nature of the environmental inputs forecast over the interval $[nT^k, nT^k + \tau^k]$ as presented by the information set $x^k(nT^k)$; in general, $x^k(\cdot)$ provides information concerning the current values of the relevant system inputs and their statistical or aggregated properties over the interval of interest;

   c) the feedback $v^{k-1}(nT^k)$ from the infimal unit identifying deviations of performance from the target values with respect of the $(k - 1)^{th}$ layer subproblem and the previous interval, $[(n - 1)T^k, nT^k]$.

5) The above sequence is repeated with period T^k; as a result, u^k is continually updated based on the current information available.

6) The above procedure extends to each layer of the hierarchy resulting in an articulated L-layer decision-making structure.

The temporal hierarchy is normally augmented by information processing, adaptive, and implementation functions such as were described for the multilayer functional hierarchy. Thus, with respect to the k^{th} layer controller, we identify the following:

1) Information Processor: The raw data from the plant and environment must be processed to extract the essential information relevant to the decision function. Processing includes: a) smoothing (to filter out random noise), b) extrapolation based on present and past data values to predict (forecast) values that reflect appropriate averaging over the time horizon for the decision function, c) aggregating to reduce volume of information flow and to simplify algorithms.

The data processing function is based on a model (again either explicit or implicit). In general, the model is to be updated periodically or on demand in order to reflect current conditions concerning the statistical properties of the signal, for example, its mean and variance values.

An important additional feature of the information processor is the monitoring of contingency events. The occurrence of such an event triggers first an assessment of the nature and seriousness of the contingency and hence whether any corrective action should be initiated, for example, an on-demand control response on the part of C^k, a modification of the control algorithm, or even a change in operating mode (for example, change from normal operation to a shutdown procedure).

2) Adaptive Function: Generally, the model on which C^k is based only approximately describes the system, hence there is need to periodically update its parameters. This is provided by the adaptive function which determines new values for the parameters every $\bar{T}^k$ units of time (where $\bar{T}^k$ denotes the adaptive period for the k^{th} layer model) based on aggregated information relevant to the local control problem. It is assumed that $\bar{T}^k > T^k$, that is, adaptation is based on the evaluation of averaged behavior of the system under the control action C^k.

It is natural to incorporate contingency control also within the adaptive function, that is, responses to contingency events that require change of control objective or mode, change of control algorithm, etc.

3) Implementation Functions: Part of the output of C^k is implemented directly on the plant or operating system via m^k.

This implies a firm commitment that is communicated as a constraint on the lower layer controllers via the control u^k. Note that the control tasks may be implemented manually, semi-automatically, or completely automatically. In any case, a prerequisite for the integrated system is that such actions be unambiguously identified through appropriate entries into the data base.

In summary, the following benefits accrue to the above approach:

a) A rational basis is provided for aggregating the variables, permitting simplification of the complex initial formulation of the problem.

b) The effects of uncertainty are reduced because the subproblems (at the lower layer) are solved based on a prediction of the disturbance input over a shorter horizon.

c) Local constraints and locally dominant factors are handled at the lowest control layer consistent with timing, information requirements, and related considerations.

d) There is a natural mechanism for the introduction of feedback of experience both in plant operation subject to the prior control and in the prediction of the disturbance inputs over the horizon period.

e) Features of the multilayer functional hierarchy may be superimposed to provide for information processing, implementation (direct control), and adaptive functions, and the handling of contingency occurrences.

f) Systems integration is achieved through a well-defined and clearcut assignment of tasks and responsibilities to the various layers of control and through information feedbacks which provide the basis for coordination of the interacting decision functions.

We note that the final integrated control system will combine into a single structure the three major features of the hierarchical approach presented in this section: the functional control hierarchy, the multilevel coordination hierarchy, and the temporal control hierarchy.

The focus of the development has been on the information processing, decision making, and control functions that have to be carried out in order to achieve an integrated production system. We have not made explicit provisions for the many ancillary functions that are a normal and essential part of any computerized system, assuming that these may be incorporated into appropriate units within the functions defined or appended as separate units.

In any event, the results represent a generalization of concept and approach which is meant to serve only as a guideline.

Thus, it is taken for granted that, in each particular design application, there will be reasons to deviate from the guideline--and this is a characteristic part of the design process.

Illustrative Example

Previous sections provide a number of examples which may be used to illustrate the hierarchical structures described in this section, for example, the order entry system, the organization of planning and scheduling functions according to time scale, the coordination of interacting production units, etc. Specifically, we consider a small part of the production planning system described previously to show the application, in very general and approximate terms, of the concepts and notation presented here.

For the purpose of notation, we make the following identificiations:

Layer 6: annual plan,

Layer 5: quarterly plan,

Layer 4: monthly plan,

Layer 3: weekly plan.

C^6: Prepare annual sales and production plans; divide annual production into quarterly allocations.

τ^6: 12 months;

T^6: 3 months;

u^7: commitments on ore and coke; sales and production policies; production goals;

x^6: production standards of shops and mills, maintenance schedules; factors influencing product demand;

u^6: annual production plan;

m^6: labor contracts; contracts for major maintenance;

v^6: cost and production data; performance evaluation over the year.

C^5: Prepare the quarterly plan; divide into monthly allocations.

τ^5: 3 months;

T^5: 1 month;

x^5: update factors affecting demand forecast, production capabilities, etc.;

u^5: quarterly production plan, determine the sizes and shapes of products to be rolled during the quarter;

v^5: experiences over the past quarter in meeting the production plan.

C^4: Prepare the monthly plan.

τ^4: 1 month;

T^4: 1 week;

x^4: information on orders received (specifications, due dates, etc.), current state of works (backlog, slab inventory, etc.), mill performance;

u^4: allocation of received orders to be processed during the current month; division of the allocation into weekly assignments, grouping of orders to maximize productivity;

m^4: production schedules for the blast furnace, coke, and sinter plants;

v^4: experiences over the past month in achieving the production schedules.

In the same manner, we can identify the elements of the weekly, daily, and shift scheduling functions. Thus, C^3 may be associated with the task of transforming the current monthly plan into a sequence of weekly plans which in turn lead to weekly production schedules for the various mills. In general, C^3 would be responsible for coordinating the conflicting requirements of the various shops and mills in the works. One element of this coordination is the grouping and sequencing of orders to maximize overall productivity of the works. Control outputs then would include the schedule of heats for the steel making shop and the set of orders to be processed by the hot strip mill. The next layer of control activity has the task of arranging the set of orders into a rolling sequence consistent with mill productivity objectives; it also has the responsibility of coordinating the schedules of coupled mill units, for example, coordinating the slab yard and reheat furnace operations with the hot strip mill schedule.

Finally, we may identify for each of the controllers in the hierarchy the functions and operations that correspond to the various components of the functional control hierarchy, for example, information processing, implementation and adaptation.

The information processing function may include the averaging of production figures, trend analyses on market demand, order projections, etc. A sudden and significant change in any of the input factors may trigger an "on-demand" reassessment of the plan in order to accommodate the new circumstances (for example, major unscheduled shutdown of a facility, labor strike, severe quality control problem). Alternately, the plan may be only modified in an ad hoc fashion to resolve a current problem pending reassessment at the regular period.

The adaptation function may be incorporated in the following ways:

a) Models used for determining production capacities, track times, performance standards, etc., are reviewed annually and updated according to

    i) evaluation of previous year's results; and

    ii) known changes in equipment, operating practice or other relevant conditions.

b) Models used for prediction of aggregated values (that is, based on probability distribution models of product mix, equipment breakdowns, quality rejects, etc.) may also be updated annually based on observations of the previous period plus consideration of any tangible factors expected to affect the distributions.

The nature of the implementation function depends, of course, on the task. For example, a task associated with long-range production planning is the placing of contracts for raw materials which are needed to satisfy the production goals. This task may be carried out by a purchasing department that then serves the role of the implementation function. Note that the purchase commitments then impose constraints on the lower layer planning processes.

Review of Hierarchical Control Concepts and Approach

The purpose of this section is to relate to some of the antecedents of the hierarchical approach described in this section and to identify some alternative hierarchical structures that have been advanced. This review represents only a small sampling of developments in the field and is not meant to be complete. Selected references are identified by author and listed at the end of this section.

Most of the underlying concepts and some of the terminology presented here have their origins in the pioneering work of

Mesarovic and his group (see Mesarovic et al., 1970; Mesarovic, 1970) that develops a conceptual and analytical foundation for hierarchical structures and multilevel coordination theory. Many of our modifications were prompted by pragmatic aspects of the application of the theory to industrial systems, for example, more explicit concern for on-line implementation and the effects of disturbance inputs, and focus on achieving feasible, suboptimal performance objectives as opposed to a "mathematical" optimum, etc.

The bulk of the literature in the field is oriented to decomposition and multilevel coordination theory and its application to optimization and mathematical programming problems of various kinds. There is a large number of references on the subject; we cite here only three books representative of the work in this area (see Wismer, 1971; Himmelblau, 1973; Lasdon, 1970). The application to scheduling problems has particular relevance to steel mill operations and some of the coordination tasks defined for the production control system may well make use of these techniques.

A closely related area of application of coordination theory is in handling the dual problem of optimization and identification (for example, of parameters of the model). We cite again only one of several references in this area (see Smith and Sage, 1974) and note that this problem, too, is relevant to our field of study, for example, with respect to adaptation of models and some prediction algorithms.

The essential features of the functional multilayer hierarchy were first described by Lefkowitz (1966). Applications of the hierarchical structure to control of process sytems are discussed further by Findeisen (1974). Extension of the multilayer concept to discrete manufacturing type systems is presented by Lefkowitz and Schoeffler (1972). This work motivated some modifications in the conceptual structure of the multilayer control system; specifically, making more explicit the role of a common data base, information processing function, and the provisions for contingency event monitoring and control.

An immediate precursor to the formulation of the temporal multilayer hierarchy is the work of Donoghue and Lefkowitz (1972). The basic contribution here was the organization of the decision-making and control functions according to the relative time scales of the required actions. Important extensions to the concepts and structuring of the temporal hierarchy were made by Cheliustkin (1975), particularly with respect to the planning and scheduling functions of the steel production system and in consideration of model aggregation relative to the hierarchy.

Williams (1971) has provided major inputs to the field of hierarchical control as applied to industrial systems. In his general formulation of the hierarchy, four levels are distinguished:

Level 1: specialized dedicated digital control,

Level 2: direct digital control,

Level 3: supervisory control,

Level 4: management information.

This structure is similar, in part, to the functional hierarchy shown in Figure 22 with, however, a stronger orientation toward the technological level of control, to the practical aspects of digital computer implementation, and to the man-machine interface. Williams currently directs a large research project at Purdue University on hierarchy computer control systems for steel manufacturing complexes, in collaboration with the major US steel companies (see Williams et al. (1974)). A structuring of the overall plant production control system being considered by the Purdue group is shown in Figure 27.

Another variant of the control hierarchy is presented by Bernard and Michael (1968). The structure is formulated in two dimensions. In one dimension is the classification of functions according to measurement, control, and communications. In the other dimension, five levels of the hierarchy are defined for each of the function categories. These levels are, in turn, organized into three groups as follows:

- emergency operation: safety control, emergency manual control, indicators and alarms, diagnostic aids;
- process operations enforcement: direct and inferred measurements of process variables, conventional and advanced control, operations monitoring and evaluation;
- operations scheduling: plant and process optimization, multiplant coordination, process supervision and accounting.

Again there are general similarities in terms of the various functions to be performed, but with significant differences in the organization of the hierarchy and in the relative detail given to the different functions.

Examples of Hierarchical Control Structures in Steel Industry

The concept of a hierarchical control structure found early motivation in the steel industry, starting with the application of digital computers to implement various operational control and process control functions in the hot strip mill (for example at the Spencer Works of British Steel Corp.) (see Miller (1966)). This led quickly to considerations of integrated plant control based on a four-level control hierarchy comprising planning,

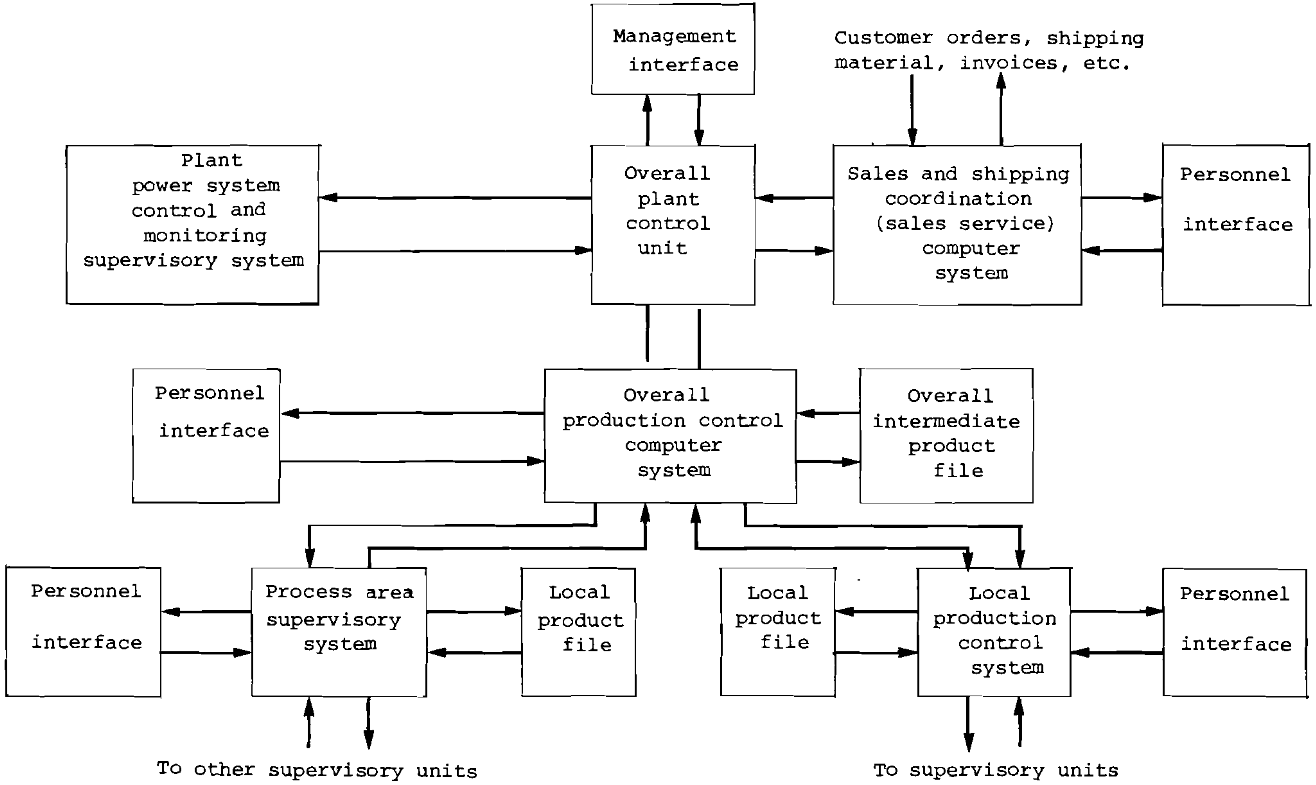


Figure 27. Overall plant production control system.

scheduling, production control, and process control functions, along with a variety of ancillary tasks related to record keeping, operator communications, accounting, etc.

The approach, considerably developed and expanded upon, has found manifestation in many of the new, modern steelworks. A typical example of a highly automated and computerized system is shown in Figure 28. Only the part of the system dealing with steel making, slabbing, and strip products is shown in the diagram and much of the detail has been omitted for purposes of clarity. There are almost replicate structures to that shown in the figure for the plate mill, section and wire rod mill and the pipe and tube mill--and these too have been omitted to simplify the diagram.

The system is organized in four levels, as follows:

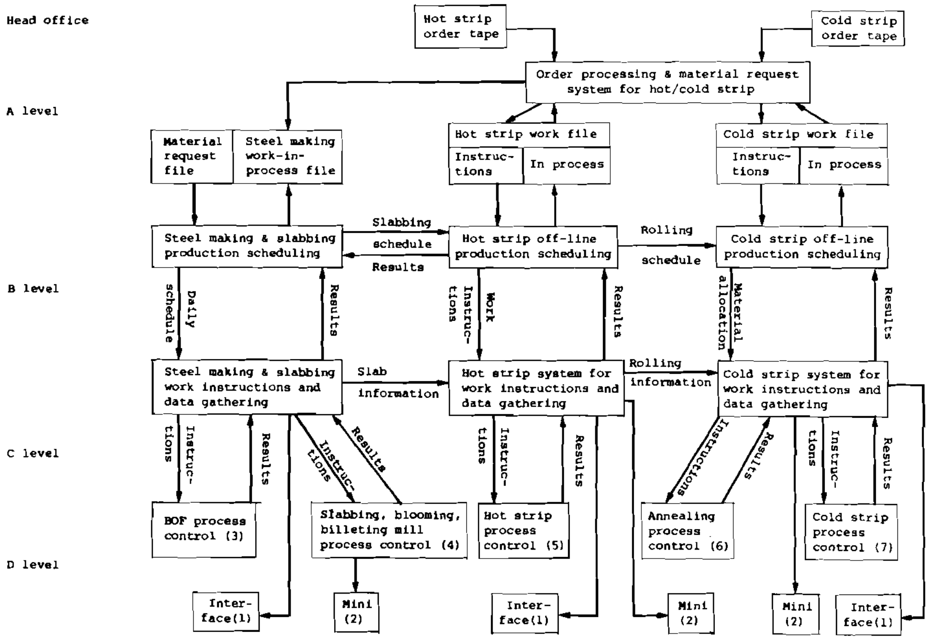
A Level:	order processing, 10-day production schedule, material requisitioning, order status, shipping, various reports;
B Level:	data gathering, daily and shift schedules, allocation of semiproducts to customers orders;
C Level:	preparation and display of work instructions, data gathering, reports;
D Level:	operations control, process control.

Computing facilities for the A, B, and C levels are located in the works computing center; the D level computers are located on the mill floor. The order entry system is located at the head office which communicates order tapes for each products group to the appropriate order processing system of the A level.

We make the following general observations:

1) The system is very hardware oriented; specifically, each block (or group of blocks at the A and B levels) denotes the functions carried out by a separate computer. There is an ordering with respect to the size and number of computers employed at each level; that is, there tend to be fewer separate computers but they are of progressively larger size as we proceed up the hierarchy. Indeed, at the lowest level, there is a number of minicomputers assigned to dedicated, special purpose tasks.

We note that, in distinction to this direct association of level with the computer configuration, the consideration of hardware has not been a dominant factor in the hierarchical structures developed in this section, and does not appear explicitly in their formulations.



Legend for Figure 28.

(1) Man-machine interface:
  includes keyboard, printer, display panel, auto I/O signal, etc.

(2) Minicomputer:
  Positioning control
  Sequence control

(3) BOF control:
  End-point control
  Charge calculations
  Operating instructions
  Production control information
  technical report

(4) Slabbing, blooming, billeting mill control:
  Scheduling
  Combustion control
  Mill setting and sequence control
  Production control information

(5) Hot strip mill control:
  Reheat furnace control
  Mill pacing
  Mill setting
  Adaptive control
  Spray control
  Coiler setup
  Technical report

(6) Annealing process control:
  Combustion control
  Timing control
  Production control information
  Technical report

(7) Cold strip mill control:
  Mill setup
  Adaptive control
  Tension control
  Automatic sequence control
  Technical report

Figure 28. Computerized control system for modern steelworks.

2) The information flows follow the general pattern of the hierarchy described in this section: decisions and control actions proceed from supremal to infimal control units, with information feedback on the results of prior actions going in the reverse direction. There are also horizontal channels of information flow whereby an interacting unit at the same level may receive information on the decisions of other units that affect its own decision making. For example, the hot strip mill production scheduler receives information from the steel making shop on the slabbing schedule; it, in turn, sends back information concerning its results with previous slabs as they may affect future schedules of the steel making shop.

3) The man-machine interfaces are a very explicit and important part of the integrated system. This again reflects the hardware orientation; in our formulation of the system, the operator-computer communications requirements are implied through the information processing functions.

4) Other aspects of our structure, for example, considerations for the effects of disturbances and contingency events, coordinating control of interacting production units, and an ordering of decision making according to time scale (temporal hierarchy), are not explicitly shown on the diagram; however, most of these would seem to be integral to the functions provided.

5) Adaptive control functions are explicitly denoted among the D level computers, but not at the higher levels. It is known, however, that the models and algorithms programmed into the scheduling and planning functions are updated periodically or on demand.

SUMMARY AND CONCLUSIONS

The immediate objectives of the Integrated Industrial Systems Project were 1) the development of some general concepts of integrated systems control, for example, multilevel and multilayer hierarchical control concepts; 2) the study and evaluation of international experiences in integrated systems control; and 3) the development of a case study based on the steel industry.

The motivating factors for the integrated systems approach were:

1) increase of productivity and operating efficiency;

2) improvement of product quality (and quality control);

3) effective utilization of resources (for example, raw materials, energy, labor);

4) compliance with technological and environmental constraints;

5) ability to adapt to time varying conditions of the plant or the external environment;

6) maintenance of system integrity, that is, the assurance that the production facilities remain viable in the face of unusual or catastrophic events.

Among the results of the first year's effort are:

1) The preparation of a state-of-the-art survey of integrated systems control applied to the steel industry based on visits to steelworks and research institutes in many different countries, discussions with leading practitioners and theorists in the field, literature reviews, etc.

2) The formulation of new results concerned with the temporal multilayer control hierarchy; these results were strongly motivated by the steel study.

3) The holding of an international conference on the state-of-the-art survey at IIASA June 30-July 2, 1975.

The experiences of the State-of-the-Art Survey tended to support the expectations outlined above. Thus, the integration of the planning, scheduling, production, and process control functions is credited with improving the performance of steelworks by increasing yield, reducing equipment idle time, decreasing the stock and labor requirements, improving product quality, and decreasing the production lag time. The main part of the increase in performance is achieved through the computerized systems for order processing, loading, and scheduling of the plants, and through the operational control systems. The long-term, medium-term, and annual planning functions performed by the head office influence the general economic position of the company through proper allocation of resources and orders among the steelworks. However, these planning functions have only an indirect influence on equipment productivity and idle time, and order delivery delay time.

The integrated control systems approach, in spite of its contributions to improved efficiency and works productivity, has not yet been broadly applied in the steel industry around the world. The only fully integrated systems (at the works level) were found in Japan; in other countries, the level of integration appeared to be much lower. This may be attributed to economic factors, prevailing attitudes toward computerization, resistance to any changes from traditional practices of decision making and control, availability of manpower and resources, and various other factors which have already been discussed in this report.

In a number of steelworks, process control systems have been implemented without consideration of the computerization and integration of the production control, scheduling, and planning functions. This can be explained, on the one hand, by the complexity of the integration problem, and on the other by the lack of general concepts and effective methodology for the design of integrated control systems.

People developing the computerized control system are often thoroughly versed in their particular fields of specialty but may have limited familiarity with the characteristics and requirements of other specialty areas that must also be considered in the design and use of an integrated system. Thus, to develop a process control system, a detailed knowledge of the technology is required; these systems are usually designed by the manufacturer of the technological equipment, often in collaboration with an instrument company. In developing managerial systems, specialists in management, organization, and planning are required who have a thorough understanding of the specific features of a given plant, and experience with its general environment. What is typically lacking are people with cross-disciplinary expertise who can inter-relate and coordinate the various disparate components of the overall production system. This situation is reflected in the observation made earlier that all existing systems of an integrated type were designed and implemented by the steelworks staff, and that there are no engineering companies advertising their ability to build such systems at the present time. The situation can be improved by formulating general concepts and guidelines for structuring the system and by developing systems methodology and engineering design methods to achieve an effective and useful integrated systems control.

Some concepts and analytical tools described in the report relate to the multilevel and multilayer hierarchical structuring of the system. We consider this as a very important first step in developing a general methodology for integrated control system design. The hierarchical approach provides the basic framework within which the large, complex systems control problem can be decomposed and the subsequent subproblem solutions integrated to achieve the desired result. In particular, three distinct formulations of the hierarchical structure are considered: the multilevel control structure, the temporal multilayer structure, and the functional multilayer structure.

In the multilevel control structure:

1) the complex plant system is decomposed along lines of weak interaction;

2) the resulting subsystems are coordinated to reconcile local control objectives to overall goals;

3) inherent to the structure are feedbacks that compensate for changes in interaction variables, disturbance inputs, and time-varying parameters;

4) the subsystem controllers act to satisy local constraints and to optimize with respect to local performance criteria;

5) each controller serves to maintain aggregated variables at values determined by its supremal unit, and, in turn, specifies the constraints, criteria, etc., for its infimal units.

The temporal multilayer control hierarchy partitions the control problem according to relative time scales. The structure provides:

a) a basis for aggregation of models and variables;

b) a means for reducing the effects of uncertainty with respect to future inputs and events;

c) a mechanism for feedback of experience;

d) a criterion for distributing information/data according to local needs; and

e) a basis for allocation of local details and control tasks to appropriate units in the hierarchy.

Finally, in the functional multilayer control hierarchy, the original control problem is replaced by a set of simplified and approximate subproblem formulations (for example, implementation, optimization, adaptation, and self-organization functions); integration of the subproblem solutions to satisfy the objectives and requirements of the original problem is then achieved via information feedbacks from the operating system.

The theoretical development is still very incomplete, however, a great many unsolved problems remain. Many of these relate to definition of the hierarchical structure and to construction of the mathematical models, considering the different time scales. One problem related to the temporal multilayer hierarchy is the uncertainty of the available information as a function of time. The longer the time period, the higher the uncertainty of the information we have. But, considering limited resources, the "optimality" of the plan increases with increasing planning time horizon. Thus, the solution can be found by trade-offs between "plan optimality" and information uncertainty. A problem closely related to the above is the defining of the time horizon for production process evaluation. Over a long time horizon, some of the disturbances influencing the process being averaged may have zero means, although over a shorter time horizon their time varying behavior may have very significant effects on the process performance.

Different time horizons for planning and control problem solution require constructing mathematical models with different time scales, thus having different variables and structures. How to construct these models, and how the inputs and outputs of models with different time scales should be interfaced, are also unsolved problems. To solve the problem for one time horizon may involve decomposition, for example, constructing a set of interrelated models, which should also be interconnected somehow with models for other time horizons. The time scaling and decomposition of models is a problem not only for planning but also for operational control, since different production operations have different time responses and different cycling times. Of great importance is the problem of determing planning standards. These standards should be established in accordance with results previously obtained. If the standards are too rigid, there is always a possibility of failure in realizing the plan. If they are too "soft" the capability of the equipment will not be fully used, resulting in decreasing production efficiency.

Standards should take into account the likelihood of some non-coordination of production operations, for example, because of the effects of uncompensated disturbances. The standards should have a built-in tolerance, that in their turn should be estimated by analyzing the real process performance. Since the implementation of computerized control and decision-making systems reduces the frequency of non-coordination, the magnitude of the tolerance can be decreased, thus improving the planning result.

The algorithms used to solve order processing, loading, scheduling, and operational control problems tend to be of a heuristic nature, and in many cases reflect the methods used by traditional "manual" control. It seems obvious that as these algorithms are replaced by algorithms based on optimization techniques, the resulting performance attained by the system should improve. Hence, there is an incentive to develop more generally effective optimization routines, particularly, for real-time computer applications.

There is a number of examples of highly computerized, integrated systems control applications in the steel industry and these provided the reference base for much of the discussion on "advanced practices" presented in this report. Some general observations are given below:

1) There is a large number and variety of computers arranged in a very explicit hierarchical structure. The control tasks are distributed according to temporal and functional considerations.

2) The information flow paths are well defined with instructions/controls proceeding down the hierarchy, and with information and feedback of results going up.

3) Embedded in the system are adaptive functions at every level--some are formal and explicit, others informal and implicit.

4) The system is highly computerized, but this does not mean that it is completely automated. The human plays an essential role at all levels of the structure; a) as decision maker where judgmental and experience factors are difficult to quantify and model, b) as overseer to ensure that abnormal occurrences are properly perceived and appropriate corrective actions taken, and c) carrying on, in general, all such tasks and responsibilities to which his talents are particularly suited.

5) An important part of the computer-based system is an effective set of interfaces for a) providing the operator/decision maker with ready access to all pertinent information by which he can interpret the state of the system, and b) means by which the operator/decision maker may input his actions and decisions for implementation on the system.

Finally, we comment that hierarchically structured integrated systems presently exist and others are being implemented. However, their design tends to be ad hoc and intuitive. We would like to think that the development of more rational and analytically based methodology for systems design would lead to more complete and more efficient integration, for example, resolutions of questions concerning a) criteria for decomposition, b) means for coordination applicable to systems operating in real time, c) criteria for model simplification and aggregation appropriate to its level in the hierarchy, d) criteria for determining the periods of control action for each layer, e) integration into the hierarchical system, considerations of information flowrate requirements, and data base organization and management, and f) many similar questions.

This review does not include problems of selecting hardware, nor those of communications and information processing based on this hardware. These problems require special study which was felt to be outside the scope of the present project activity. Thus, we thought it necessary to investigate the problems of functional structuring and its general concepts before attempting to resolve questions of software and hardware structures.

In summary, we found the case study in steel to be very instructive. It reinforced some of our prior conceptual thinking with respect to the hierarchical control structure; it also motivated some new insights and formulations of the structure. This study represents only the first phase of a series of proposed case studies, for example, a mechanical engineering system and a chemical processing system--each expected to point up new aspects of the problem of integrated systems control leading to the formulation of some general concepts and guidelines applicable to a broad class of industrial systems.

References

Bernard, J.W., and G.M. Michael (1968), *Organizing Multilevel Process Control Systems*, Workshop on Multilevel Systems, IEEE Systems Science and Cybernetics Conference, San Francisco, Calif.

Cheliustkin, A.B. (1975), *Temporal Hierarchy of the Production Management System*, RM-75-72, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Donoghue J.F., and I. Lefkowitz (1972), Economic Tradeoffs Associated with a Multilayer Control Strategy for a Class of Static Systems, *IEEE Trans. on Auto. Cont.*, AC-17, 7-15.

Findeisen, W. (1974), *Multilevel Control Systems*, Panstwowe Wydawnictwo Naukowe, Warsaw (in Polish).

Himmelblau, D.M., ed. (1973), *Decomposition of Large Scale Problems*, North Holland, Amsterdam.

Lasdon, L.S. (1970), *Optimization Theory for Large Systems*, Macmillan, New York.

Lefkowitz, I. (1966), Multilevel Approach Applied to Control Systems Design, *ASME J. of Basic Engr.*, 88, 392-398.

Lefkowitz, I., and J. Schoeffler (1972), Multilevel Control Structures for Three Discrete Manufacturing Processes, *Proc. Fifth IFAC Congress*, Paris.

Mesarovic, M.D. (1970), Multilevel Systems and Concepts in Process Control, *Proc. of the IEEE*, 58, 111-125.

Mesarovic, M.D., et al. (1970), *Theory of Multilevel Hierarchical Systems*, Academic Press, New York.

Miller, W.E. (1966), Systems Engineering in the Steel Industry, *IEEE Trans. on Systems Science and Cybernetics*, SCC-2, 9-15.

Nagasawa, I., and T. Kobayashi (1973), Computerized Integrated Production Control Systems, *Third Interregional Symposium on the Iron and Steel Industry*, UNIDO, Vienna.

Smith, N.J., and A.P. Sage (1974), Hierarchical Structuring for System Identification, *Information Sciences* (January).

Williams, T.J., ed. (1971), *Interfaces with the Process Control Computer - The Operator, Engineer, and Management,* Instrument Society of America, Pittsburg, Pa.

Williams, T.J., et al. (1971), *Systems Engineering of Hierarchy Computer Control Systems for Large Steel Manufacturing Complexes,* Vols. I, II, Report No. 63, Purdue University, West Lafayette, Ind.

Discussion

Kopetz

Mr. Cheliustkin, to what extent has this system been already implemented in steel mills, or wherever you saw the system in your visits?

Cheliustkin

Some of the things we have shown describe existing systems implemented in a particular plant. Then, in other cases, we have shown a composite system, prepared by combining different parts of systems implemented in different plants. We have combined in our composite system the most advanced practices observed in different places. Thus it is difficult to estimate what part of a system belongs to which plant. For instance, in one of the Japanese plants we found a noncontact system that indicates the position of each overhead crane. On the other-hand, we found a crane dispatching system operating with a less modern crane positioning system in a European plant. By combining the most advanced parts of these two systems we got the "new system" described in the review.

Lefkowitz

I might comment that we adopted the policy for our state-of-the-art review, not to identify by company or by country the specific aspects of the advanced state of the art being described. The feeling was that if we tried to catalogue what different people were doing and what was going on in different countries, thereby of necessity making comparisons, we would get into difficulties with somebody saying that we missed this or that, or that we didn't give them sufficient credit for their accomplishments, and etc. Our purpose essentially was to try to identify the "what" and "why" of the current state of integrated systems control rather than the "who" or "where". Now, in informal discussion, of course, we may discuss specific experiences and observations; however, for the written document we felt that it would be a mistake to be specific with respect to what this company is doing or that that is the status of development in the socialist world compared with the market economies, or whatever kind of comparison one might be induced to make. Perhaps some of you may want to comment about this decision.

Wieser

There seems to be a contradiction between what D.H. Kelley said before and the presentation of A. Cheliustkin. If I understood Kelley correctly, he said there is no one system, there are different systems, and you were impressed by the influence of environment on what is going on within the system and within the company. Now in this more technical presentation it seemed, or at least I got the impression, that you actually cannot say what is the best solution for combining aspects of different systems. So the impression I got is that there is a technical solution of what the optimal system would be. On the other hand, we were told that companies work very differently depending on the environment that they have and in which they have to work. But somehow this information seems to get lost when we only combine the optimal aspects of different systems drawn together from different kinds of systems.

Lefkowitz

That is a valid comment. I think that our Report should have included more interpretive analyses that might have addressed questions of the kind raised by Mr. Wieser. For example, we might have commented on the influence of various factors with respect to the extent of computerization, the directions that were pursued in the development of different systems, the ways in which the economic system, or the nature of the company (for example with respect to size and product mix) affected the results etc. We tried to do some of this in the present Report; hopefully the final Report will be more complete in this respect, particularly if we can get inputs from you people. I feel that it is possible to bring in this interpretive aspect without necessarily being specific with regard to what is the state of development in a particular company or country.

Wieser

Well, I feel that, if you want to draw final conclusions you should be able at least to say that within certain systems this solution is more optimal than another solution or maybe that your point of view is the optimal solution regardless of the social system, economic system or whatever.

Lefkowitz

I agree with you, and this is what I meant by an interpretive development of the Review, and I think perhaps we should have expanded on that. We will still try to do it. Now, Alex Cheliustkin would like to make some remarks concerning these problems.

Cheliustkin

It seems to me that the purpose of this review is not to show what is done by particular companies (for example, Austrian or Japanese), but to show in which direction engineering work should proceed in the future. We are not considering economic or social conditions at the present time; however, we would not propose to go to the highest level of automation without taking these conditions into account. We have noted that in Japanese steelworks a very high productivity is reached, something like 750 to 800 tons per employee per year. In Europe the average is about 250. Certainly, if European productivity jumped suddenly to the Japanese level there would be a big problem of unemployment. Of course, this fact should be considered.

de Gregorio

I would like to know if the organizational control takes into account the model that the lower level of process control needs for supervision. It seems to me that the model that you have to keep in your program does not sufficiently take into account the organization of feedback at the lower level.

Cheliustkin

I will try to answer this question. Certainly when you are investigating operational control levels you always have to consider what kind of constraint you have and that some of the constraints are caused by the control of the lower levels. A good example of this is described in a paper that has been distributed to conference participants. This paper shows how system analysis may be applied to obtain higher productivity and better quality of hot rolled strip by considering constraints imposed by technology used in different production stages.

de Gregorio

My second question is this. In other industries, for example, the electrical industry, in the case of power distribution, the operational control also takes a possible failure of the system into account; in other words, it is possible to run the system leaving enough margin to the units so that if something happens, it is not completely catastrophical. Though this introduces some inefficiency in the system, you can go on with your program without completely disrupting the goal. It seems to me that this kind of goal has not been studied enough.

Lefkowitz

Well, that problem has been very carefully studied by the electrical industry because of some serious mishaps that have occured in recent years. In fact, here is a system that has expanded so greatly that it has taken on attributes of a large-scale system in which many things that might happen as a result of a mishap or malfunction are really not predictable. The stability properties and the propagation of transients through such systems are still not well understood; as a result, in the US we had the Northeast blackout which, I think, shocked a lot of people.

I think that there are aspects of this problem in other industries and surely in the steel industry, as well--perhaps not in as explicit or obvious a way. For example, allowances are made in the scheduling operation for the possibility of an urgent rush-order or the breakdown of a piece of equipment. The question is whether and to what extent this is to be done in an ad hoc manner or whether it can be incorporated into the integrated control system as a rational, analytic procedure similar to what is now being done in some systems in the electrical power industry. I think this is a very important area that should be reflected in the design of a truly integrated control system.

de Gregorio

I remember, a few years ago that some people proposed a research study for the purpose of getting data on the reliability of different components of the plant. It is only on the basis of real data that you can build up some methodology.

Lefkowitz

You mean data concerning the reliability of technological equipment?

de Gregorio

Yes, technological equipment. My objection was that the technology is so diversified that one really cannot determine scheduling times in a universally applicable manner. It is extremely difficult. The transmission of the procedural goal reveals the weak points, but the goal depends on a great many factors. However, I think the idea was just to start to study this problem of the control methodology of the plant, to cope in the best way, especially with the large plant. But we cannot work through with it. In the past, they tried to make a rigid plan of all the foreseen difficulties; they worked out what to do whenever something happened. But now, with the continuous casting plant and slabbing, you can have a wide diversification in the same plant. Which is the more practical approach in order to decide on the system design?

Cheliustkin

We have seen a rolling mill that does not have any emergency manual control and the mill is controlled automatically by the computer. We were told that reliability of technological equipment is much lower than that of the computer system.

Bruch

Mr. Cheliustkin, you described a system for flat products. What experiences do you have with the manufacture of profile products?

Cheliustkin

In one of the Japanese steelworks an entirely new technology for the production of wide flange beams has been developed. This technology can be achieved only by means of computer control. It is the only example I have seen of a computer application for the profile mill process control. The computer calculates the temperature distribution over the cross section of the beam and estimates the elongation of the metal in different parts of the cross section, resulting in a decrease in the internal stresses in the beam.

de Gregorio

Do you mean calculation of temperature on-line?

Cheliustkin

They have calculated all this by means of a model that is continuously adapted to the process. So it is essentially on-line.

Kovacs

Let me quote a sentence from your Review: "The objective, ultimately is to develop a conceptual framework for design of integrated control of industrial systems that will lead to the formulation of general guidelines applicable to a broad class of industrial systems". I have two points. One is that if, for example, the machine industry and the steel industry are in the same class, then a given guideline may not be really applicable to either of them. Just to give you one example--

in one of the steelworks they tried to apply a data system that was basically developed for the machine industry; they have since decided to develop a completely new system, throwing out practically everything of the original system because it was not usable. The second point is that it seems to me in reading this statement that IIASA is, in a way, leaving the steel industry project. I have the feeling that, at this point, it would start to be really useful to continue this project. To add one more comment, I think that the involved technology is very relevant, and that scheduling efforts, at least the general ones, leave out a significant part of the subject.

Lefkowitz

First of all, let me say that the Review reflects project objectives that were initially formulated. Unfortunately, the real income available to IIASA eroded by about 25% from budget expectations because of the combined effects of inflation and depreciation of the dollar. As a result, we have had to make significant cut-backs with respect to our plans for the project beyond the first year. Secondly, as we noted earlier, we recognize our limitations with respect to personnel, resources, etc., We feel, however, that by developing networks of collaborative activities among various research groups in institutes, laboratories, and universities around the world, we can indeed be effective with respect to our goals and aspirations. In this scenario, IIASA, capitalizing on the international aspects of its membership, serves as a clearing house and forum for information exchange, and plays the role of catalyst, initiating joint research activities and getting people with common interests together.

We looked at steel as an initial case study. We hope that we can get started on a second case study drawn from the area of machine building or mechanical engineering. This might proceed over the next year or so, again with strong external collaboration. Following this might be an additional case study in the area of chemical processing. These studies would provide us with background experiences on which to formulate our general guidelines. In summary, we hope that we can achieve our objectives through a combination of in-house research and a collaborative out-of-house network of people and groups working in the common area of interest. This mode of operation has already proved successful in some of the other IIASA projects. With regard to the question of technological models, we have felt from the very beginning that getting involved to this degree of detail would be well beyond our capabilities--except as we might perform a clearing house function with respect to what is going on elsewhere.

Kelley

I feel that Mr. Kovacs, by the manner in which the question was phrased, was also asking whether or not we were trying to set up a single philosophy and a single system of planning and scheduling which would be applicable equally to all forms of industry. Now, this is clearly not what we were trying to do. What we considered to be a reasonable objective was to study one or two industries initially to get some feel for the problems and suitable types of solutions, and then, as it were, maybe move up a level and develop some general theories of control systems. The approach we have studied may be seen as a subset of some general theory and this is not the same as saying the same control system will work for all industries. But we may come to the conclusion that this is indeed possible and that we will be able to apply the results to other industries with what you might call a general approach. That, I understand, is what we are trying to do, but we have only taken one tiny step down that road.

Lefkowitz

Thank-you. This is essentially what we meant in the context of "formulating general guidelines".

Cheliustkin

Something we have already done in the theoretical field is described in Section 3 of the preliminary Review. This theoretical investigation presents a general approach to the problem of structuring the integrated system control. This approach can be related to any industry.

Phaff

Mr. Cheliustkin, can you tell us how common the use of fully automated hot strip mill equipment is?

Kelley

I would like to answer, if I may. There are no fully automatic ones at all. There are many models or programs which produce feasible schedules, but I do not think we visited any steel plant where a man did not look at the final schedule just to be quite sure.

Cheliustkin

The ultimate decision is always made by a man.

Kelley

We did visit one or two companies where it was stated that this review was really a ritual rather than a necessity but they were not going to change in the near future. I think that a large number, perhaps three fourths of such works that have hot strip mills do have some program which produces a reasonably feasible solution, but nobody now is confident enough to operate the schedule without any manual checking. I think that is a fair answer.

Hübner

Are there any multilevel systems that have no hierarchical structure?

Lefkowitz

All the systems that I have described imply a hierarchical structure, but one can also think of a multilevel system that is not hierarchical in the sense that the flow of information and of commands does not follow the paths I have indicated. You may have alternate actions carried out by different components of the unit which do not follow the supreme, inferior kind of structure, but I have excluded that kind of consideration from my structuring of the system because I think basically it does not fit in.

Williams

Would that be parallel operating units at different levels?

de Gregorio

Or at the same level?

Williams

He said multilevel.

de Gregorio

Yes, but it could be possible in an office where there is a head and a member of components. If there is really a hierarchical structure, then the components of the office do not speak to one another but have to speak to their leader to get information for their operations. From the point of view of the human organization, the hierarchical structure is, in a sense, a limitation.

Williams

The hierarchical structure does not imply though that you have to go up before you can come down. You can still go across.

de Gregorio

The key is the connection that everybody is communicating on the top and the top is dictating individually.

Lefkowitz

I think there ought to be a distinction made in this, between what happens to the control functions and the commands as opposed to what is done with the information. I think inherent in all these structures is a notion of a flow of commands from the top down, expressed in terms of defining local objectives, or local constraints, or allocations, or what have you in such a way as to influence the infimal units to act cooperatively in the common good. It is a basic idea, but there is no reason why you cannot have a lateral flow of information; I do not exclude this possibility if it serves a useful purpose.

Now, as a matter of fact, in the hierarchical structure for the Kimitzu computer system there is a lateral flow of information (for example, transmission of slab properties from one processing stage to the next), but the instructions or the priorities of action are from the top down. We are not talking about centralized decision making, but rather a coordinating kind of decision making. In general, whatever can be done locally should be done locally, and part of the motivation for the various hierarchical structures presented here is that they provide a rational basis for organizing the system with this idea in mind, reserving only the essential coordinating functions for the supremal units of the hierarchy to make sure that overall goals and constraints are being satisfied.

Cheliustkin

I would like to make a few additional comments. We may consider that there are two types of hierarchy. The first exists when you decompose the problem into several subproblems in order to ease the solution. The second exists when you consider the various time horizons associated with process evaluation. For instance, preparing the yearly plan, we evaluate the process for a time duration equal to one year by means of a model appropriate to this time horizon. For another time span there must be another model. To show how the time periods for process evaluation influence the model performance, I will give one example.

Several years ago a dynamical model for the blast furnace was developed, and statistical methods were used to estimate the model's parameters. The process of investigation was to last for several months, and finally a special processor was built with the productivity of the blast furnace as the output. The result obtained by the model was very instructive. Averaged over a period of several months, the output of the model corresponded very closely to the actual output of the furnace, but for a short period of time the model output deviated significantly from that of the furnace.

Why did this happen? There are many variables influencing the performance of the blast furnace, but in averaging these variables over long periods of time, their expected values tend to zero. Over a shorter time interval a model must include more variables. Thus, when evaluating the process for different time scales, you have to build different models. However, to obtain a more optimal solution, the longer time horizon should be considered. Thus, long-term planning is to be used, based on a model with little detail. But the nearer we are to the practical implementation of the plan, the more detailed a model must be. So, that is another reason for the time hierarchy.

Kopetz

Let me ask a question concerning the hierarchy. Hierarchy means that you have a set of subsystems that are in some relation to each other. What criteria are you actually using to establish your hierarchy? Is it time? Is it order of command? Is it anything else?

Lefkowitz

The criteria were different for each of the three aspects of the hierarchy that I described: the functional, temporal, and the multilevel. In the multilevel case, which is closest to the question you asked, I would say that the decomposition into subsystems is very much influenced by the way that industrial systems normally evolved over time. In fact, the evolutionary trend of process design is such as to generate weak interaction linkages between the subsystems in order that the system will be operable by traditional means, for example manual operation and conventional controls. Thus, there is a natural tendency to make use of the existing structure in the implementation of systems integration.

One likes to think that new process design would be motivated by considerations of how the decision making and control can best be carried out, which would lead to structural, temporal, and functional decompositions that were more efficient from the standpoint of the decision-making and control arguments that I have advanced; but this is something that one looks for in the future.

With respect to the temporal hierarchy, much of it is also a result of an evolution of standard practices. You could ask the question "Why do most steelworks have an annual plan, a quarterly plan, a monthly plan, and so on?" There are, of course, some practical reasons for the established spectrum of time scales.

Integrated Systems Control: The Purdue Experience

Theodore J. Williams

INTRODUCTION

The most important recent trend in automatic control in industry has been the attempt to bring whole plant complexes under unified coordination and control and even to attempt to mechanize entire company operational supervision systems, utilizing a hierarchy of computers such as illustrated in Figure 1. Such developments have necessitated a whole new level of consideration of the problems which are inherent in multilevel, multi-input computer control systems and in the theory of the optimization of large scale systems. Of primary importance here are

1) the effects of such systems on lower level supervisory functions and on personnel practices, and
2) the specifications and requirements for the computers themselves and for their associated software.

These must be thoroughly studied in order to make such systems successful. A project recently initiated at Purdue University in cooperation with the major steel companies of the United States is an attempt to help satisfy these needs and further this field.

Method of Attack

The method of attack being carried out in this research, is a close cooperation between a university group (Purdue University's Schools of Engineering through their Laboratory for Applied Industrial Control) and a group of major steel companies (Armco Steel Corporation, Middletown, Ohio; Bethlehem Steel Corporation, Bethlehem, Pennsylvania; Inland Steel Company, Chicago, Illinois; Jones and Laughlin Steel Corporation, Pittsburgh, Pennsylvania; National Steel Corporation, Pittsburgh, Pennsylvania; Republic Steel Corporation, Cleveland, Ohio; and United States Steel Corporation, Pittsburgh, Pennsylvania).

The companies will supply all pertinent plant data necessary and will also provide examples of operational supervisory structures selected for study by the group. Purdue will carry out the major part of the analysis involved with the consultation and active involvement of their industry associates. A total of 10 professors and 15 graduate students are currently involved in the study.

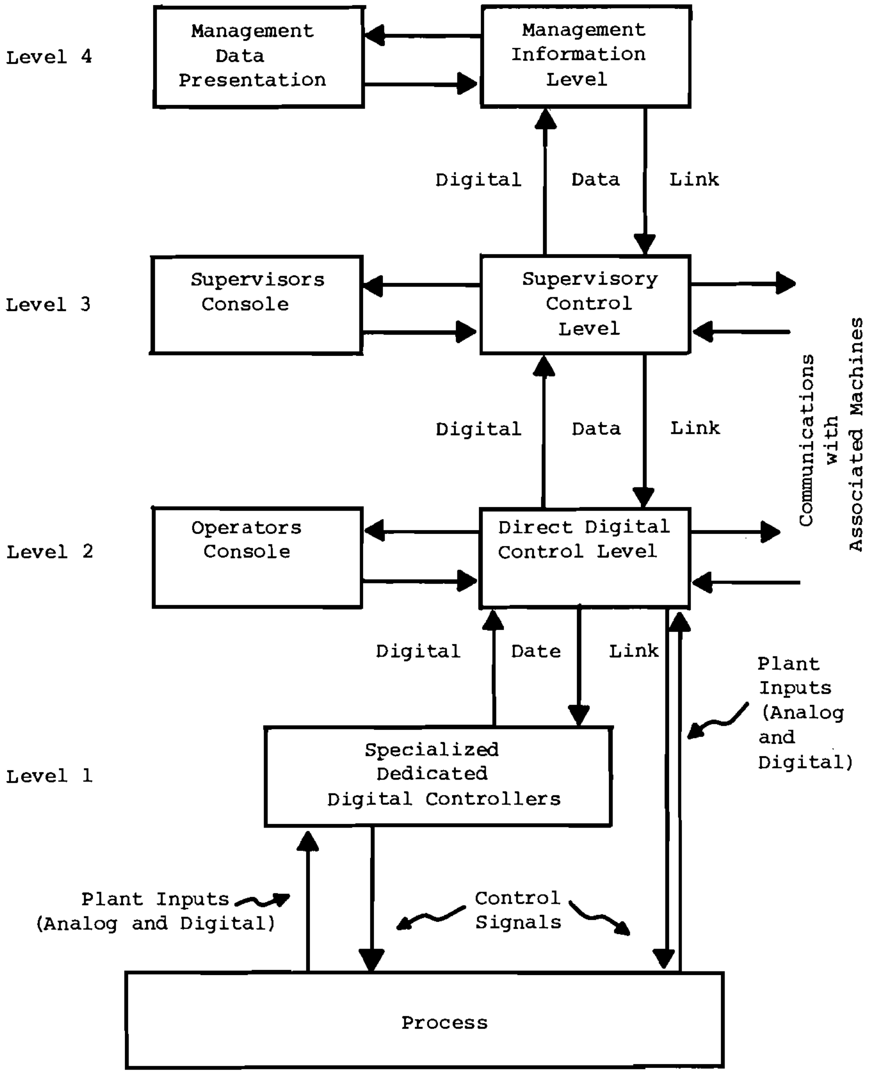


Figure 1. Outline of a hierarchy organization for a standardized process computer control system.

This project will concentrate its study on the three major branches of the overall steel mill process control problem:

1) methods for the analysis of the large-scale systems involved in steel mills for the purposes of their mathematical modeling. Use of the resulting models to develop advanced control systems for the processes involved;

2) evaluation of the capabilities of hierarchy control systems versus the needs of the overall steel mill complex. Use of the results for the preparation of a suitable specification for the hardware and software required to give the desired coordinated overall control of the complex being studied; and,

3) a thorough investigation of the details of the present operational management structure of the plant along with the details of the supervisory planning techniques, development of the effects of the use of a hierarchy computer control system on the supervisory management functions, presentation of a modified supervisory management structure which takes advantage of the capabilities of the computer system proposed in 2) above.

Successful completion of this research should have the potential for a major monetary influence on the steel industry. Inland Steel Company (one of the sponsoring companies) estimates, derived from their experience with small present-day computer control systems and their discussions with their sister companies here and abroad, indicate a conservative payout of nearly $1.5 billion per year with full implementation of the concepts discussed herein. This is, thus, a vital problem requiring an early solution to provide the steel industry the help it needs to allow it to effectively combat its very strong foreign competition and to attain the promised benefits.

In addition to the dramatic productivity increases stated in the steel company's estimate just mentioned, implementation of a major hierarchical computer control system such as is discussed here should make major savings in the massive energy requirements of a major steel mill by achieving a much better coordination of the operation of successive units in the production line. This will allow much less time for intermediate plant products to lose their high energy content, thus reducing greatly the need for reheating of process items between successive production stages as well as a more efficient use of the furnaces themselves.

The Basic Steel Mill

A total steel mill complex as developed by a single large American steel company even at one plant site produces a multitude of different iron and steel products using a vast array of processes. A number of these products, however, are specialty products, with a relatively small volume of sales, and the equipment used to produce them is similar to the equipment used to make the larger volume products.

In the interests of reducing the overall size of the project undertaken here, in view of the limited time and personnel available, the Purdue group and its sponsors decided to concentrate the work of the project on what can be termed a "basic steel product mill", that is, all the equipment necessary to produce a major product line (here, cold rolled sheet), in a wide variety of grades, thicknesses, properties, etc. Since the results from such a study can readily be adapted to include other lines of products and their corresponding equipment needs, this definition and limiting of the plant being considered should in no way detract from the overall value of the study and, at the same time, will go far toward assuring its enventual completion.

The set of rules and assumptions used in specifying the basic plant are listed in Table 1, and the major flow of steel in the plant itself is outlined in Figure 2.

Task Definitions and Assignments

Figure 3 divides the total project as envisioned here into a set of coordinated tasks. While individual research teams are assigned a set of specific responsibilities, all personnel must keep themselves fully informed of all aspects of the research, and close contact between research teams with full cooperation and information exchange between them will be maintained.

Figure 3 also defines the responsibilities assigned with the tasks by outlining on a sketch of a typical overall plant hierarchy computer system the areas of cognizance of each of the seven major tasks discussed. Thus, as pictured here, task 1 is concerned with process mathematical model development. Task 2 is concerned with the dynamic control of the individual processes; thus, it involves most of the work of levels 1 and 2 of the hierarchy which are Direct Digital and Specialized Digital Control. Task 3 is related to sales order processing and its incorporation into production scheduling. Task 4 concerns itself with a study of the most appropriate optimization techniques; thus, it is concerned with levels 2 to 4. Task 5 treats all supervisory and management control aspects of the hierarchy, that is, levels 3 and 4. (Note that task 5 must depend on many of the finding of tasks 3, 4, 6, and 7 as indicated by the location of the corresponding boxes on the figure.) Task 6 will study the overall reliability of the total control system, and task 7 will treat the man/machine relationships of the operator's, supervisor's, and manager's consoles and other interactions with the computer system.

Table 1. Rules and assumptions used in specifying the basic steel mill for study under this project.

---

1. A sufficient supply of raw materials--iron ore, coke, limestone, fuel, etc.--will be assumed to be available. Since most raw material purchasing and stockpiling operations in US steel mills are divorced from short term scheduling decisions of the plant operations, this is considered to be a reasonable assumption.
2. The blast furnace will be used for iron ore reduction. The computer control system envisioned would accommodate varying analyses of blast furnace charging materials available.
3. The basic oxygen furnace (or BOF) and the electric furnace will be the only processes used for refining pig iron to steel. Since these processes represent about 70% of steel making today (a figure which is rising steadily) this is considered a reasonable limiting rule for the project.
4. Conversion of molten steel to slabs for the rolling mills will be carried out by a continuous casting machine and a combination of ingot casting, ingot storage, soaking pit, and slabbing mill processes. These will be considered to operate both alternately and in parallel as two separate alternatives.
5. Forming and related operations will consist only of the following processes:
    a) Slab conditioning,
    b) Reheat furnace,
    c) Hot strip mill,
    d) Pickling line,
    e) Cold reduction mill,
    f) Heat treating,
    g) Temper mill,
    h) Finishing operations,
    i) Product inventory and warehouse,

    with the end result of producing hot and cold rolled sheet steel in the wide variety of gauges and properties normally involved in a steel mill operation.
6. No consideration will be given at this time to the following:
    a) Coating operations such as painting, tinning, or galvanizing,
    b) Blooming or plate mills and their products,
    c) Bar, rod or tube product forming mills,
    d) Structural shapes.
7. The requirements for monitoring of shipments via transportation media after they leave the steel mill site, while an important function, will not be treated here.

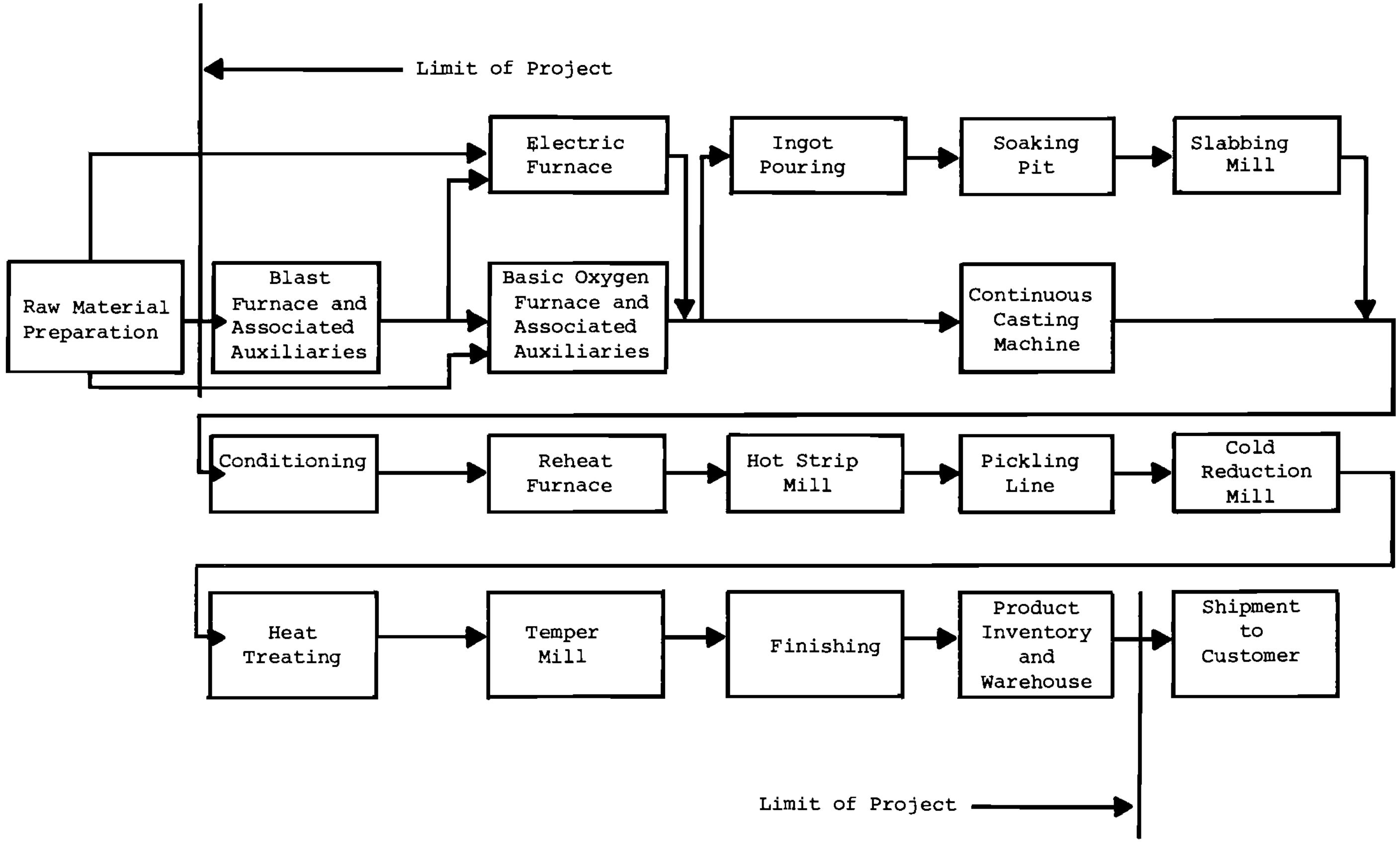


Figure 2. The major flow of steel in the basic steel mill being considered in this project.

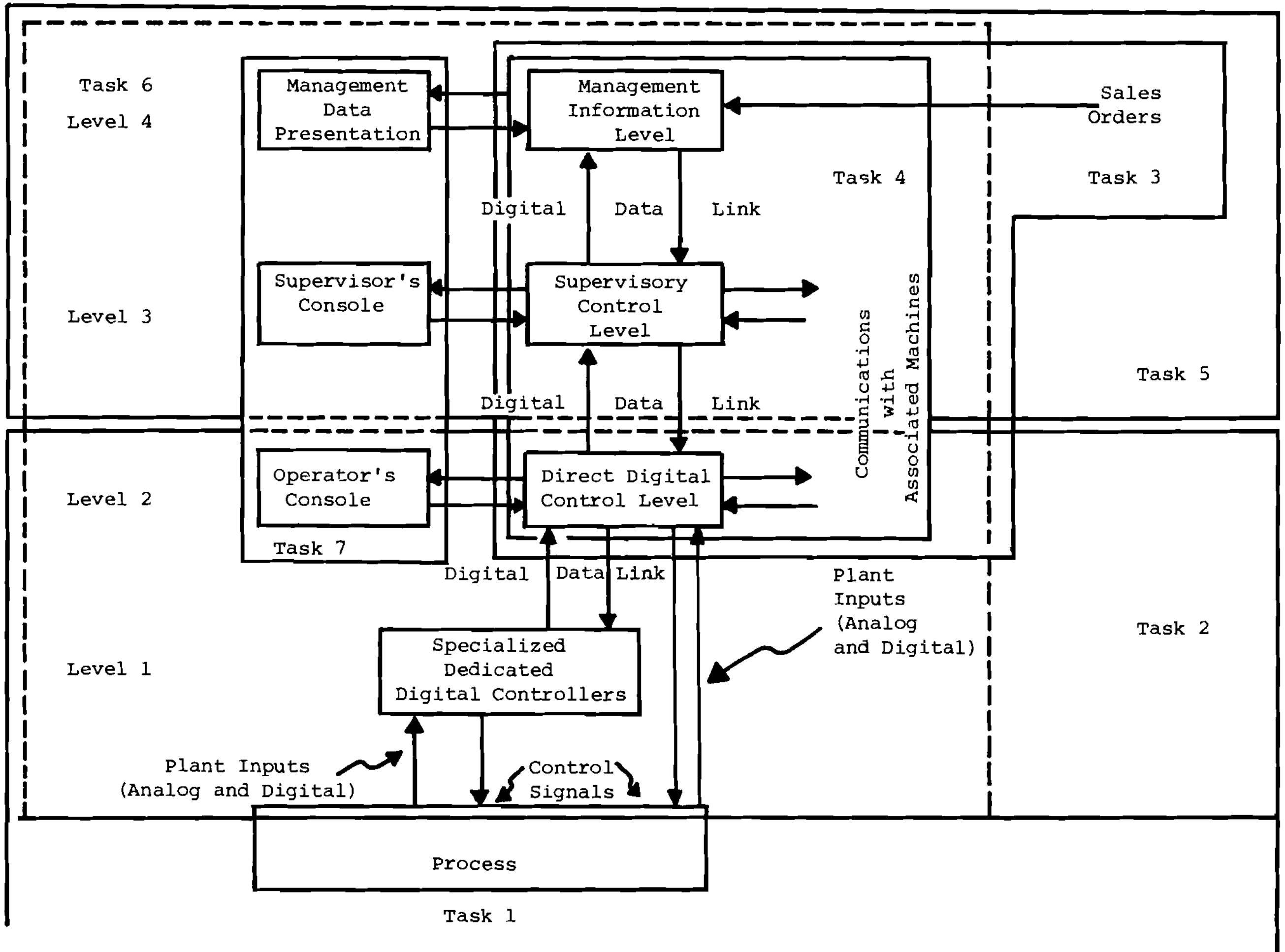


Figure 3. Task assignments in hierarchy control system development.

PROPOSAL FOR A HIERARCHICAL COMPUTER CONTROL SYSTEM

A major objective of this project is the development of the specifications for an overall digital computer based control system for the steel mill complex. The system as finally developed should make possible the hierarchical control of the overall plant in the manner outlined by Figures 1 and 3. To help coordinate the work of each of the tasks of the project with the others, preliminary proposals concerning such a control system will be detailed here. These proposals will serve to initiate discussions between the university research group and the industrial sponsors group and will help direct these discussions toward the correction and refinement of these proposals. As such, it is expected that these proposals may possibly be considerably changed before the development of our final proposal at the conclusion of the project.

Automatic control of the modern steel mill, whether achieved by a computer based system or by conventional means, involves an extensive system for the automatic monitoring of a vast number of different variables operating under a very wide range of process dynamics. It requires the development of a large number of quite complex, usually nonlinear relationships for the translation of the plant variable values into the required control correction commands. Finally, these control corrections must be transmitted to a large set of widely scattered actuation mechanisms of various types that, because of the nature of the steel manufacturing processes, involve the direction of the expenditure of extremely large amounts of energy. In addition, plant personnel, both operating and management, must be kept aware of the current status of the plant and of each of its processes.

As was shown in Figure 2, the basic steel mill can be readily divided into several different areas of activity chiefly centered on the separate processes and their related raw material and product inventories and their utility suppliers. Because of the physical size of these processes and the required space for the related inventories these process areas are often separated by considerable distances. For these reasons essentially the same distinction will be maintained in the design of the related control system, at least for the lower level members of the hierarchy involved.

In outlining the basic control system that we have in mind, we will use the current concept of a widely distributed set of isolated functions carried out by small and inexpensive microcomputer systems. These systems will be highly redundant to preserve the integrity of the control system in the face of the possible failure of any one unit. Their work will be coordinated by a set of successively higher level, and probably larger, computers connected together and connected to the distributed remote control computers by an extensive plant communications system.

The lower levels of the hierarchy as proposed here will be based on the recent developments in the large scale integration of electronic circuits that has produced micro-computer models with a very high capability and extremely low cost in comparison to other present day systems. At the same time, communications research has produced high-speed, serial data systems that are similarly reducing the costs of multi-computer system communications. From these components, extremely reliable multi-computer control systems can be developed to automate most of the functions of a modern steel mill.

Such a system has many benefits that can be of great value when installing, operating, or altering the system. Some of these benefits are

1) flexible system configuration: distributed subsystems may be modified, replaced, or deleted without upsetting the rest of the system.

2) graceful degradation: failure in one of more components or subsystems does not cause the entire system to fail.

3) high systems reliability because:

   - easy to add parallel redundant units and subsystems that can be incorporated to back up and duplicate the functions of the main components and subsystems.

   - transmission of partially processed plant information, allowing decreased data rates (since processors are distributed to functional areas and only processed information need be sent between any two subsystems), and use of error detection codes that permit any fault or casualty condition in the system to be detected and identified by the processor in its area of responsibility.

4) lower cost owing to:

   - simplified hardware configuration packaging, since processors need not be large because of reduced processing requirements of each processor.

   - simplified software because functions are carried out by several small, locally responsible processors, not by a single large machine that must perform all of the control functions and calculations within the entire control system.

- large scale integration technology.
- multiple use of standard components. Many different subsystems can use identical hardware to perform varied functions.
- ease of incrementally increasing capability since units may be added to the system without drastically interfering with the functions of the rest of the system.
- simplified installation requirements since common data channels can be used for processor-to-processor communication. This eliminates the need for individual multiple-wire cables between any two units.

The application of the above principles to the specific requirements for the steel mill unit processes results in a system architecture that incorporates several micro-computers to perform control and monitoring functions within each functional area and a set of supervisory minicomputers controlling the overall system and performing the necessary calculations and interrogation functions to support and maintain optimal control performance as mentioned above.

A general sketch of the computer control centers and the data highway common communications channels is shown in Figure 4. Note that all subsystems have access to four separate communications channels since information can be passed in either of two directions through either of the two cable loops comprising the communications channels.

An Outline of the System Envisioned for Local Control

An outline of the functions to be included within each of the areas discussed above is presented below.

Computer Equipment Requirements

Figure 4 is a typical block diagram of the distributed computer control system proposed for each basic process area. A remote control center will be assigned for each of the major process functions within each of the process areas. (A sketch of the type of equipment proposed for each of these process functions will be shown below in Figure 5.) Table 2 presents the systems capabilities that must be incorporated into the computer systems and their associated programs to achieve the capabilities necessary to match the needs presented. As can be seen this is a completely redundant system in terms of sensors, multiplexers, and controllers to assure the maximum possible reliability. This redundancy combined with the additional fail

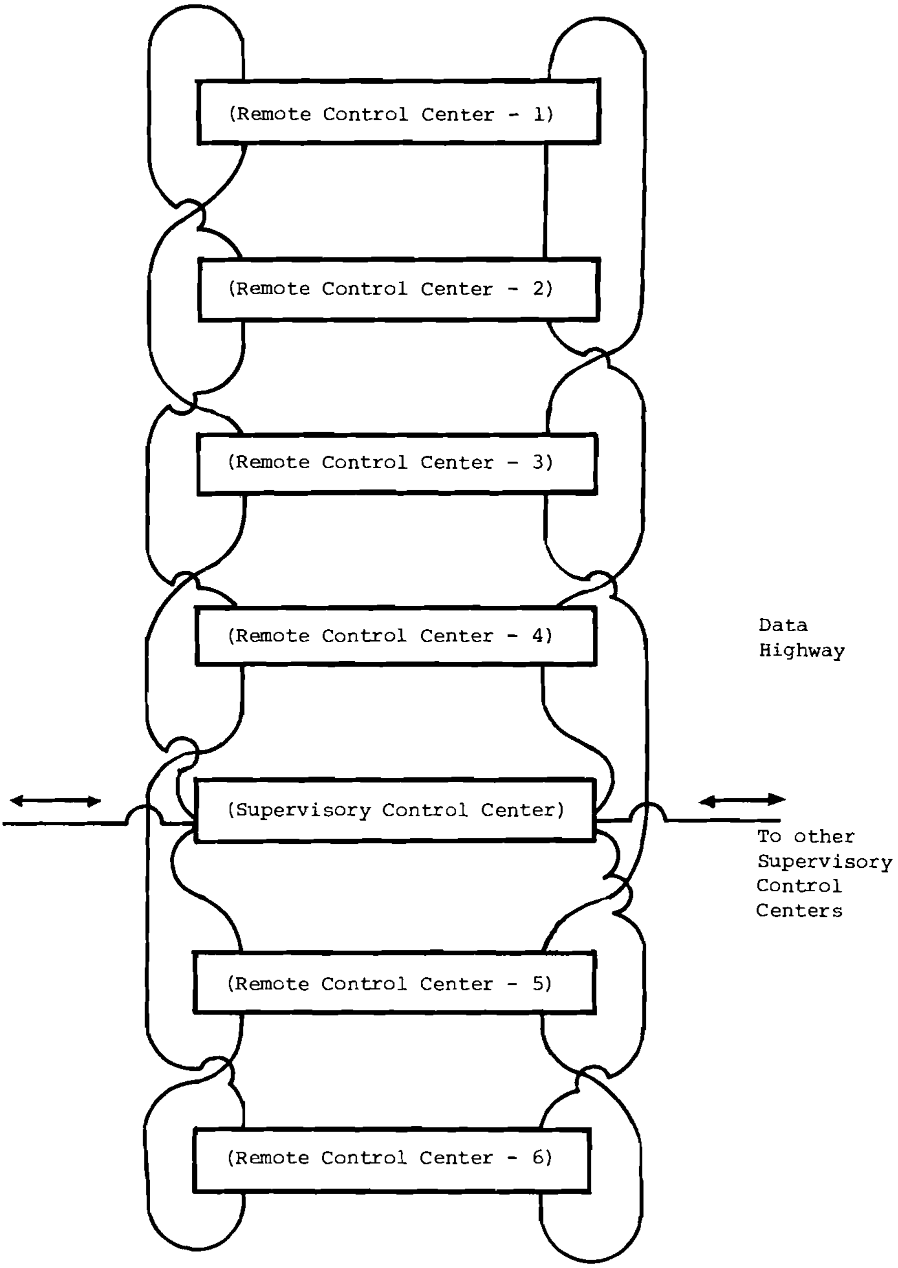


Figure 4. General sketch of a set of computer control centers and data highway communications channels.

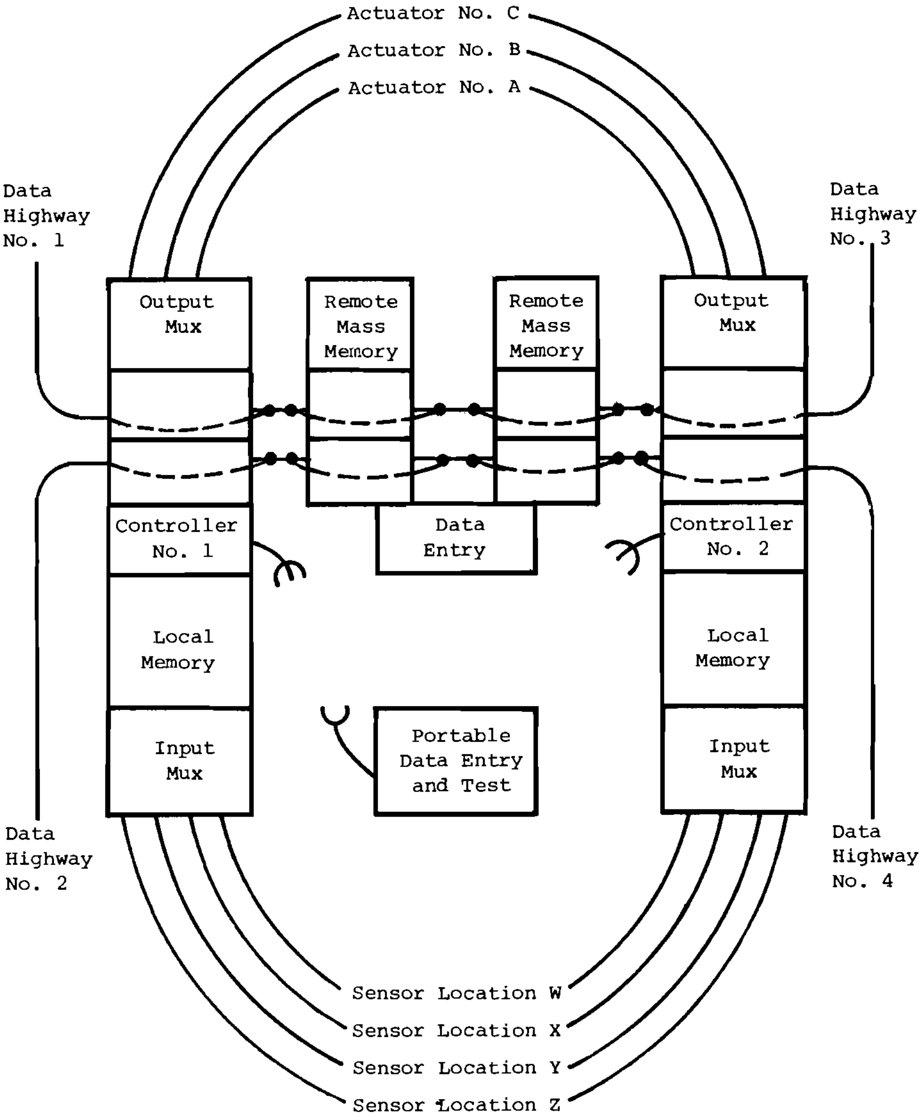


Figure 5. Typical control center (representative of all blocks in Figure 4 except the Supervisory Area).

Table 2. Some capabilities required of the micro-computer and mini-computer control systems.

---

1. Either of the two redundant micro-computers in each area will be capable of operating from any one of the four data cables of the communications channel of Figure 4.

2. Either of the two redundant micro-computers in each area will be capable of carrying out all control functions of its area of responsibility.

3. Either of the two redundant micro-computers in each area will be capable of driving either one of the two available CRT systems (see Figure 5).

4. Either of the two local micro-computers in each area will be capable of being addressed by a portable interrogation device for operability testing, readout of constants of system, circuit checks, etc.

5. In common with the central (that is, supervisory) computer system any functions of the computer systems should be checkable from the external portable interrogator. It should be possible to adjust any systems constant by this method.

6. Diagnostic programs selected by the main (that is, supervisory) computer must be able to be run on any of the subordinate micro-computers as an operational check.

7. Main (that is, supervisory) computer system functions:

    a) Logging of preselected important data;

    b) Logging of new actions during the operation of the plant;

    c) Selection of optimum strategies of operation;

    d) Diagnostics and control of maintenance tests and corrective measures;

    e) Presentation and output of normal operational data as required by regulations;

8. On-line diagnostics of self and of related systems.

9. All systems will operate on a large unit replacement maintenance system basis rather than through actual electronic repair of components and cards. (It should be noted that micro-computer technology will permit such a replacement type maintenance policy at less cost than current practice.)

---

safe[1] capabilities listed in Table 2 should adequately assure this necessary capability.

System and component test and adjustment capability is provided by two different sources. First, a portable interrogation device is supplied to test the operability of the components and their circuits and to test the constants of the system. Any system constant should be capable of being adjusted using this device. Secondly, the supervisory computer maintains a file of simulation and diagnostic programs that can test the operability of any component of the system and check the result of any normal operating routine.

The supervisory computer system must be capable of logging preselected important data and new actions during the operation of the process. It also selects optimum strategies of operation and controls diagnostics and maintenance on all parts of the system. Output of normal operational data as required by the needs of plant personnel is controlled by the supervisory computer system. All systems should be maintained on a replacement maintenance system rather than through the repair of components and cards.

Consistent with the above requirements for the control system components, Figure 5 has presented a basic controller configuration that will satisfy the needs of the system. It contains all operating systems, calculation procedures and program logic, and communication interfaces. Inputs to this controller system are provided by sensors and an operator interface as well as the data highway system. Outputs are directed to actuators, the operator interface, and the data highways. The data highway channels are redundant at each controller site and have the capability to bypass the controller so that a failure in any one controller does not cause the failure of the entire communication system. Figure 6 is a redrawing of Figure 5 to show the actual hardware connections involved rather than the functional blocks previously used to indicate redundancy capabilities.

The controllers have a parallel processing capability to enhance the reliability of the system. Each controller has a memory storage capacity of up to 16,000 words at 16 bits per word. The latest electronic technology has been assumed. Each controller can stand alone or serve as part of the data highway integrated computing and control system.

---

[1] Sufficient separation and redundancy to prevent any instantaneous total failure of the computer system.

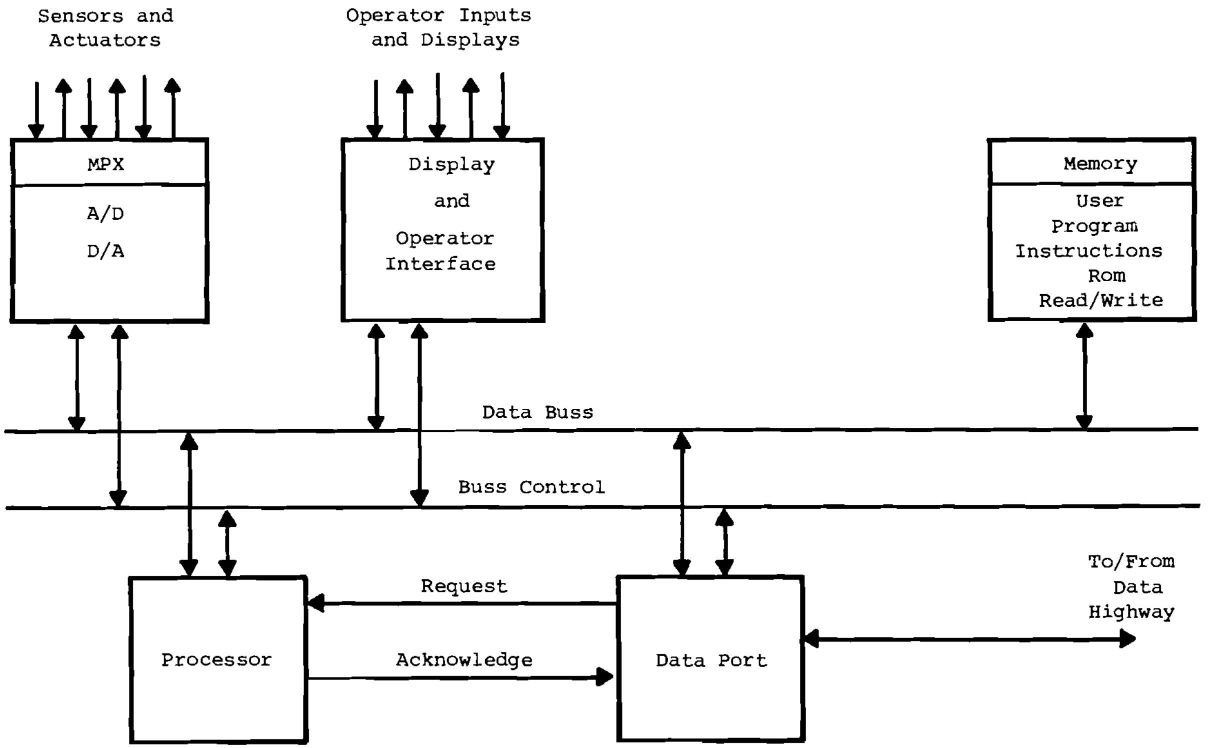


Figure 6. Proposed process control system basic controller configuration.

Man-Machine Interface

The justification for the above type of control presentation centers has been based on the economic benefits to be realized by reduced manning, improved efficiency, and higher reliability as well as other factors. However, up to now, little has been said about the operator's role in the operation of the control system itself and of the human engineering problems encountered in the implementation of such a system.

Without the introduction of computer control, the operator has displayed before him almost all the data available on the operation of the equipment. The vast quantity of this information makes it extremely difficult for the operator to absorb all pertinent data and make reliable, rapid decisions concerning the plant's operation and any necessary actions he should take. The use of the computer in controlling the system can take much of the work load from the present operator. The major personnel role is for systems maintenance. By being provided with the capability of automatic monitoring of process parameters and automatic alarms in the event of failure, the operator is freed to make operating decisions and repairs needed in the day-to-day operation of the physical plant (see Dallimonti, 1973; Halverstadt et al., 1974).

In order to introduce the operator into the operation of the control system, it is necessary to design an interface between the man and the machine (computer). The flexibility and adaptability of the digital computers proposed for the implementation of this control system makes them well suited to the inclusion of the human operator as a supervisor, monitor, and decision maker (see Williams, 1971).

There is a set of requirements and concepts for man-machine interfaces that has been well established and documented as being applicable to process control computer systems (see Williams, 1971). These requirements can be met easily in the design of the computer system and control centers without eliminating any of the previously discussed equipment or operations. These requirements and concepts for the man-machine interface (see Dallimonti, 1973) are;

1) Avoid parallel displays mounted on extended panels since they contain more information than the human operator can absorb simultaneously.

2) Process operation information should be displayed on an exception basis.

3) Compact indication of process performance or status should take advantage of pattern recognition display techniques.

4) Data should be grouped to convey knowledge of the operations of natural subsystems.

5) Alarms should be hierarchical, being selectively suppressed as a function of operating state.

6) Manual operation of most control valves should be possible as a redundant feature.

7) History of and trends in past data should be available for operator guidance but hard copy is not essential for this information.

8) Analog displays should be used for qualitative information, digital displays for quantitative information. These two forms can be mixed as required.

9) Available derived variables such as efficiency quality, etc, should be used as performance indicators rather than simple variables such as temperature, viscosity, etc.

10) A single interface should be provided with all of the functions and information available at any one location.

11) Interfaces should not be compromised to support other functions such as maintenance and management.

Availability

Components such as described here are now being developed by all of the major automatic control systems suppliers. Normal product development rates will have such devices available for public announcement in the near future and available for purchase for complete systems installations, such as is contemplated here soon afterward.

The Steel Mill Processing Area Control Systems

Each of the essentially independent processing areas of the basic steel mill (in terms of instantaneous operation) is indicated by Figure 7 which is a modification of Figure 2. Each of these units would have its own local control system as outlined above. In addition should the steel mill in question have two or more major units in parallel in any of the areas outlined in Figure 7, such as three blast furnaces or two hot rolling mills, each of the separate blast furnaces or hot rolling mills or other parallel units would have its own local control system.

A major task of any overall automation system for a large steel mill is that of tracking the individual prices of metal as they proceed through the mill and are turned into the final product desired by one particular customer. Because of the

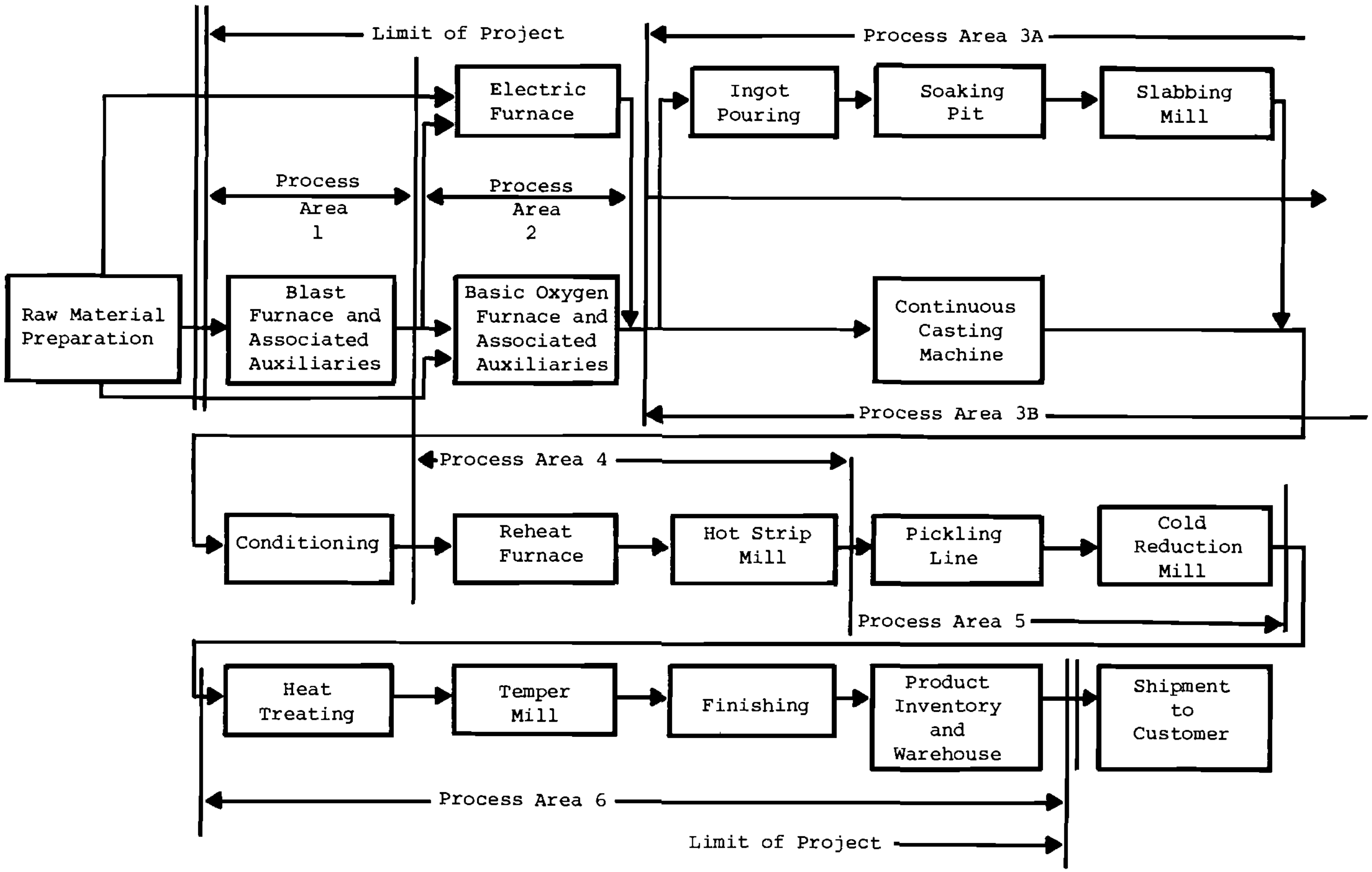


Figure 7. Modification of the basic steel mill sketch to show process control areas.

widely varying chemistry, physical properties, and dimensions possible it is essential that the correct processing be applied to each specific piece of steel and that it finally be directed to fill a particular order being held by the mill for a specific customer.

Complicating this problem is the fact that the repeated operations of the steel mill tend to destroy any means of identification that might be attached to the piece of steel by any physical or chemical means. Thus the major method must be through a constant "tracking" of the location of the piece of steel and an infallible recording of all actions that occur related to it. For this purpose an extensive file system must be devised and an associated computer based monitoring system developed. The steel also must be transferred directly across the interface between any two process areas as an individual unit whose progress can be monitored. If multiple units are transferred, or if storage occurs during the transfer with multiple access, some method of physical marking of the piece at the output of one area which can be "read" at the input of the next must be devised. If economically possible these units should be human independent.

It is at present assumed that there will be a major file associated with the supervisory system for each of the separate processing areas, as shown in Figure 8. Where there are several such processing areas of the same or alternate type in parallel, one central file may be used as shown in Figure 9.

It will be seen that the existence of parallel and alternate processing units will require the use of a local production control unit, probably a separate computer system, to coordinate, and hopefully optimize, the use of the alternate and parallel units.

The control system outlined here will achieve a major breakthrough for the steel industry only if the basic computers used themselves can essentially be identical for each remote control enter and also identical, within the class, for each supervisory control center. The widely different functions involved for the separate processes handled will be achieved through the software programming of each computer involved. Likewise it is hoped that personnel interfaces can also be physically identical but achieve their separate functions by specific programming.

Supervisory and local production control units will probably be redundant computers of the presently labelled "minicomputer" size and capability. Local product files will be redundant magnetic units, probably disks.

Production Planning and Overall Plant Control

Figure 10 presents the overall plant control unit as

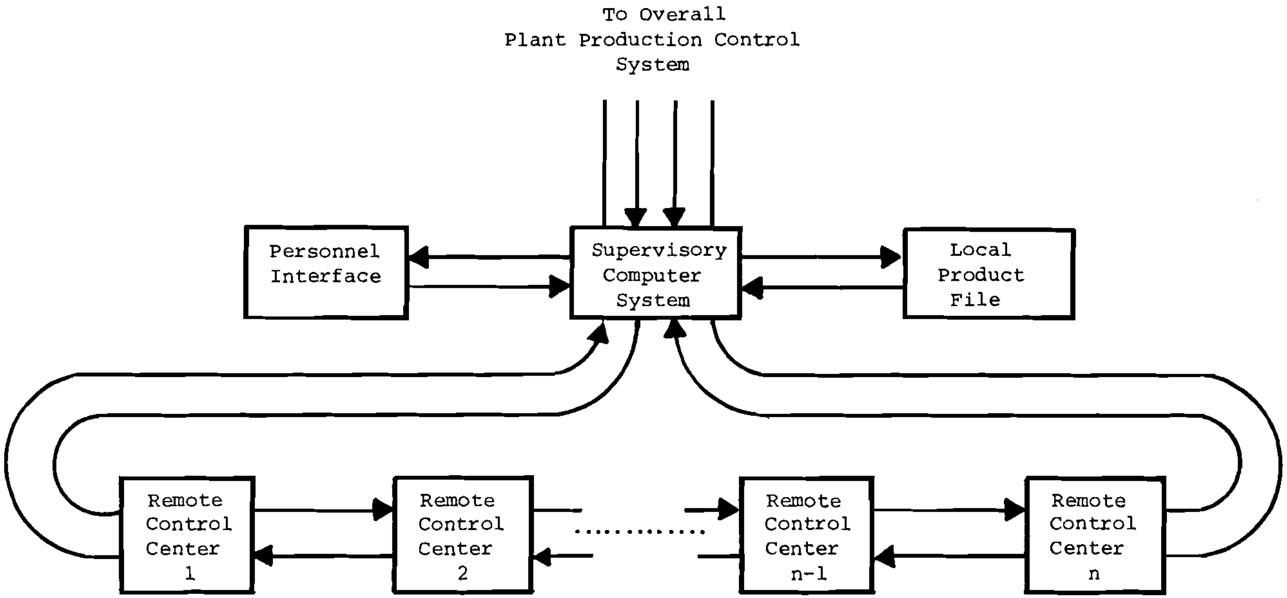


Figure 8. Sketch of the relationship of the local product file to any specific processing area.

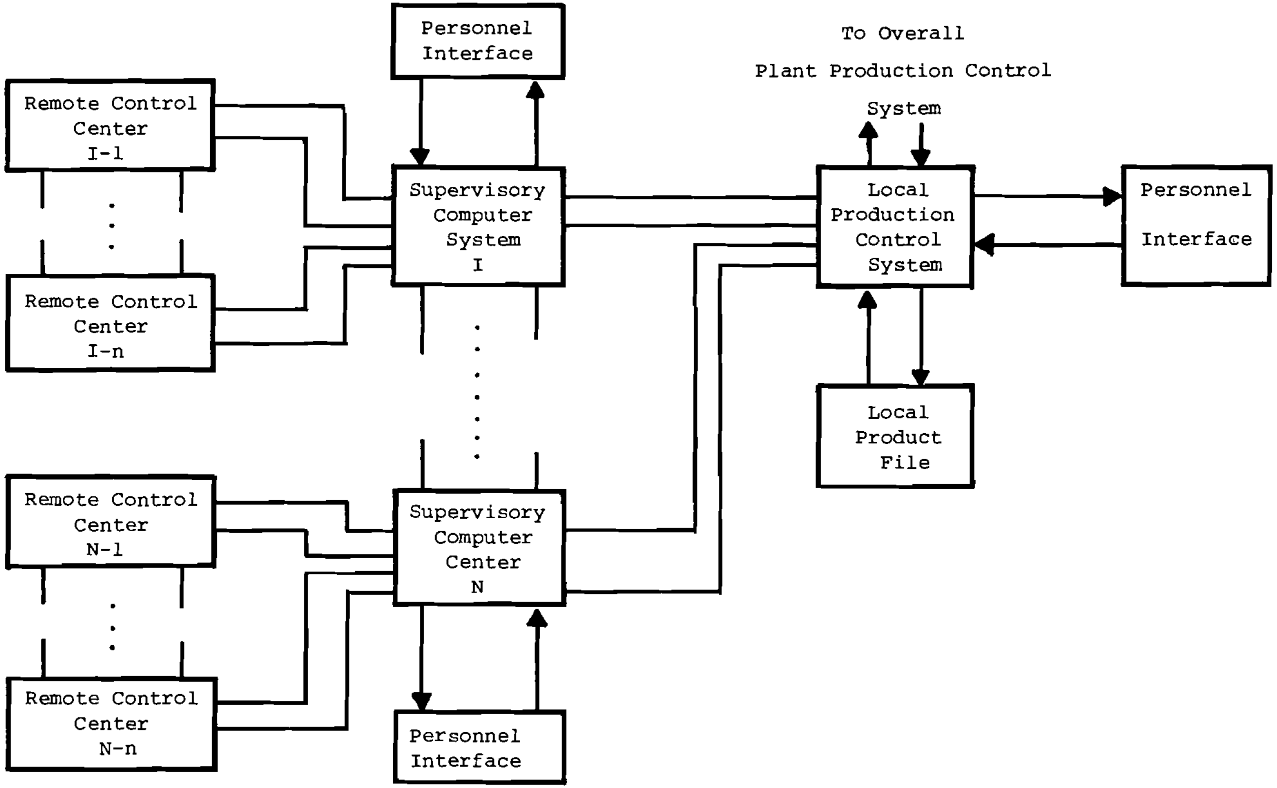


Figure 9. Sketch of the supervisory control units for a set of parallel and alternate processing units.

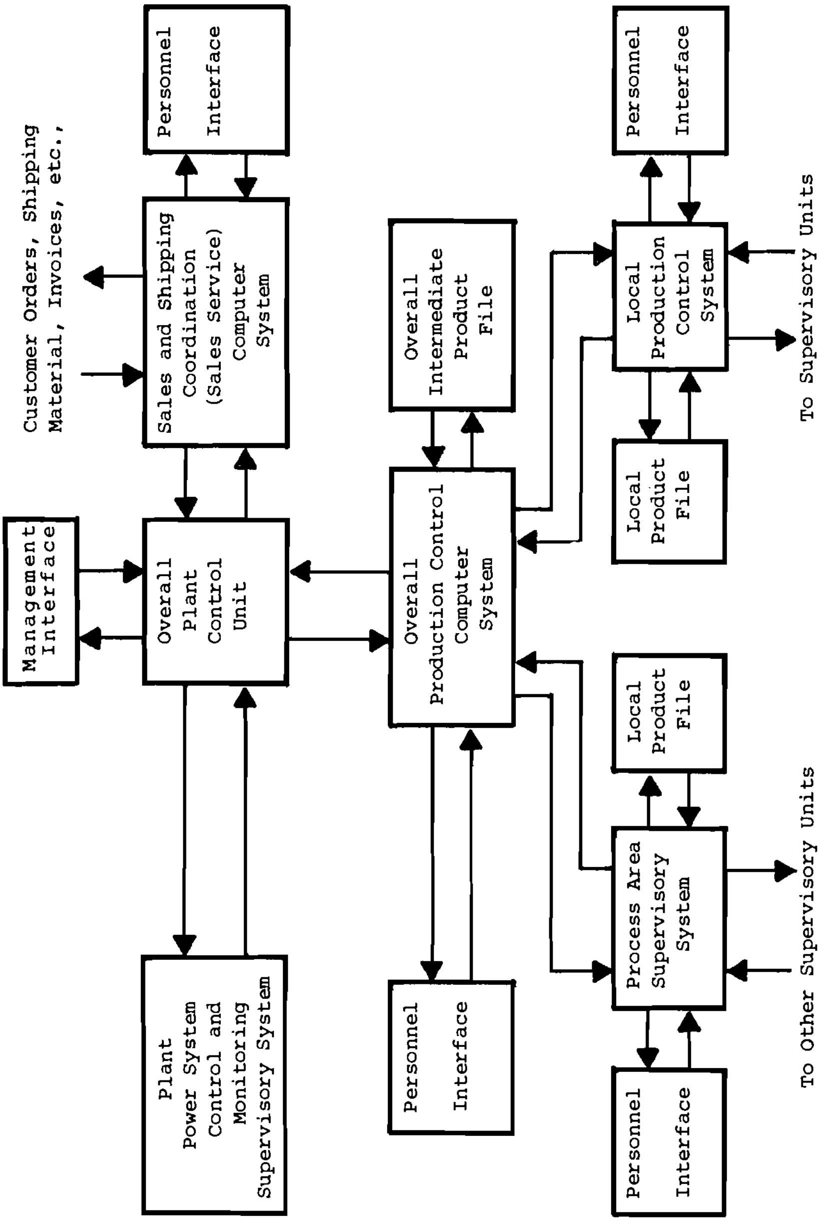


Figure 10. Overall plant production control system.

envisioned at present. This control is shown split between three major units because of the widely varying nature of the three functions involved: sales service, production control, and overall plant control.

The overall plant control unit is effectively a small communications type computer whose job it is to pass information between the other major units and to supply needed information to management as requested. The sales service and production control computers are large accounting type machines because of the nature of their tasks. Again, they will be redundant to avoid the interruption of plant functions in the event of any computer systems failure.

SOME NOTES ON RESEARCH PROGRESS TO DATE

This project is now approaching the end of the second year of work on a projected four year study. The first year was of necessity devoted to a training period for the students and their professors to learn something of the work and the problems of a basic steel mill such as we are studying. A sampling of some of the results attained to date are outlined below.

An Analysis of Instrumentation and Control Requirements for the Members of Hierarchical Computer Control System for a Steel Plant Complex

The project team on this task has been studying the problems of interfacing the computer systems at the higher levels of the hierarchy. Tables 3 and 4 and Figures 11 to 13 present some initial analyses of this problem. Based on this initial analysis we are initially favoring a multiple loop structure using CAMAC procedures for the lower members of the hierarchy and SDLC procedures for the higher members. CAMAC (see Nuclear Instrument Module Committee, March 1972; July 1972; April 1973) is a procedure developed standardized by the nuclear laboratories both in the United States and Europe. SDLC (Synchronous Data Link Control; see Synchronous Data Link Control, no date) is an IBM development receiving considerable attention at present. These techniques fit the requirements of the preliminary system proposed in Figures 8 to 10.

Integrated Production Planning and Control of Steel Making Facilities

A set of extensive simulation programs has been developed to help carry out this task. See Table 5. The extent of the basic steel mill which is modeled at present is shown in Figure 14. It is in process of being expanded to cover the complete

Table 3. Factors involved in the design of an industrial computer control hierarchy system.

---

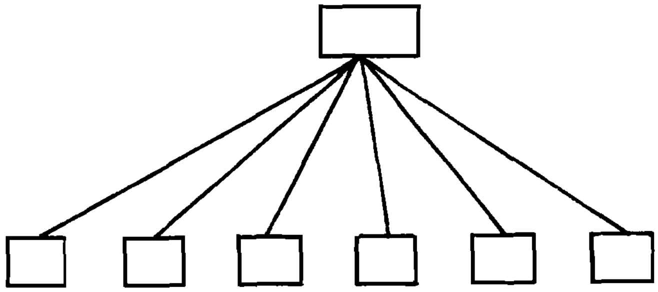
1. Goals of the Communication Network in a Computer Control Hierarchy:
    - a) Direct data exchange between computers,
    - b) Spreading the data base over the different computers for
        - Minimal duplication of data,
        - Location of the data where it is most needed.
2. Types of Data to be Communicated:
    - a) Process control data (for example, set points),
    - b) Scheduling information,
    - c) Plant information for data logging purposes,
    - d) Miscellaneous data.
3. Distinctions Between Control Networks and General Purpose Computer Networks:
    - a) Real time constraints and priorities involved,
    - b) Functional specialization of some computers--especially at the lower levels,
    - c) Use of special terminals (consoles, display stations) as elements of the network for
        - Display of information,
        - Manual intervention.
4. Network Design Topics:
    - a) Topology involved,
    - b) Type of communication desired,
    - c) Communication control procedures needed,
    - d) Network host interfacing problems.
5. Topology of the Network:
    - a) Factors determining topology:
        - Cost of communication links,
        - Ease of expansion,
        - Reliability,
        - Time constraints;
    - b) Alternative topologies being considered:
        - Multiple loop structure,
        - Centralized star network,
        - Star structure with horizontal links,
        - Mixture of the three types.

Table 4. Factors involved in the design of a multiple loop communications structure for a steel plant hierarchical computer control system.

---

1. Types of Communication Procedures Possible
   - a) Alternative Methods:
     - i) Switched versus nonswitched,
     - ii) Parallel versus byte parallel versus serial,
     - iii) Unidirectional versus bidirectional,
     - iv) Store and forward;
   - b) Some Notes Concerning Each Point:
     - i) Switched versus nonswitched:
       - High levels--choice of switched or dedicated lines,
       - Low levels--dedicated lines necessary because of signal load;
     - ii) Parallel versus serial operation:
       - Parallel = fast, expensive (short distances),
       - Serial = slower, inexpensive (long distances),
       - Byte serial = compromise;
     - iii) Store and forward:
       - Allows several messages at the same time,
       - Requires buffering in network nodes.
2. Need for Standard Communication Control Procedures:
   - a) Provides a standard method of:
     - Identifying a station,
     - Requesting permission to send,
     - Inviting to send (polling),
     - Arbitration in case of contention,
     - Error detection/correction,
     - Recovery in case of errors (for example, retransmission);
   - b) Some Standards in Use:
     - CAMAC (low level),
     - SDLC (high level).
3. Host-Network Interfacing Methods:
   - a) Via a special processor (for example, ARPANET IMP, μ computers);
   - b) Tasks involved:
     - Message routing,
     - Assembly and disassembly of messages,
     - Conversions,
     - Protocol generation and recognition;
   - c) Trade-offs to be considered:
     - Simple interface processor and higher load on host,
     - Elaborate interface processor and no additional load on host.

1A. Star Structure



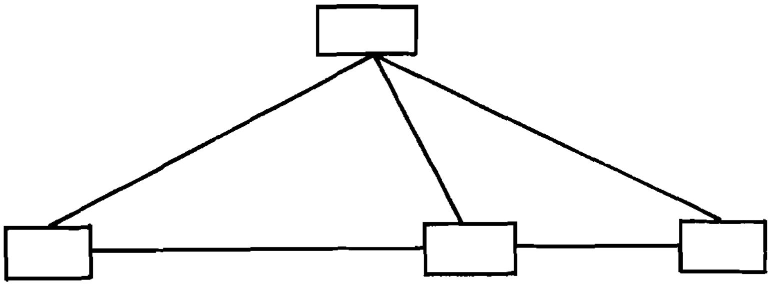
Central Control

This system has distinct advantages, for example, central file system.

Disadvantages:

- Link failure → communication interrupted,
- Large number of links.

1B. Star Structure and Horizontal Links



Advantages:

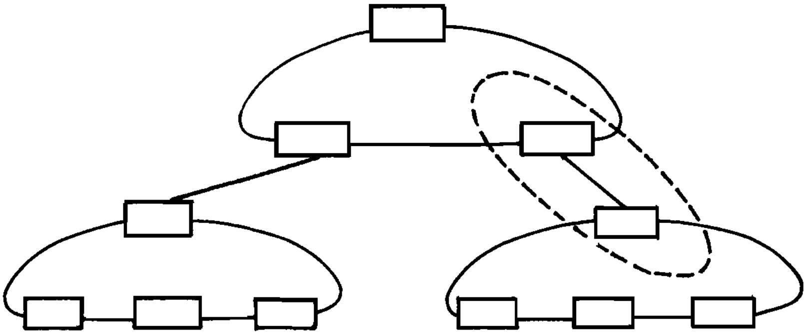
- Reliable (alternate paths).

Disadvantages:

- Large number of links,
- More complicated nodes in case of alternate routing.

Figure 11. Diagrams of alternative topologies being considered (continued).

1C. Multiple Loop Structure



Advantages:

- Reliable--connectivity is guaranteed when one link fails,
- Minimizes the number of links.

Disadvantages:

- Problem of interconnecting several loops.

Figure 11. Diagrams of alternative topologies being considered.

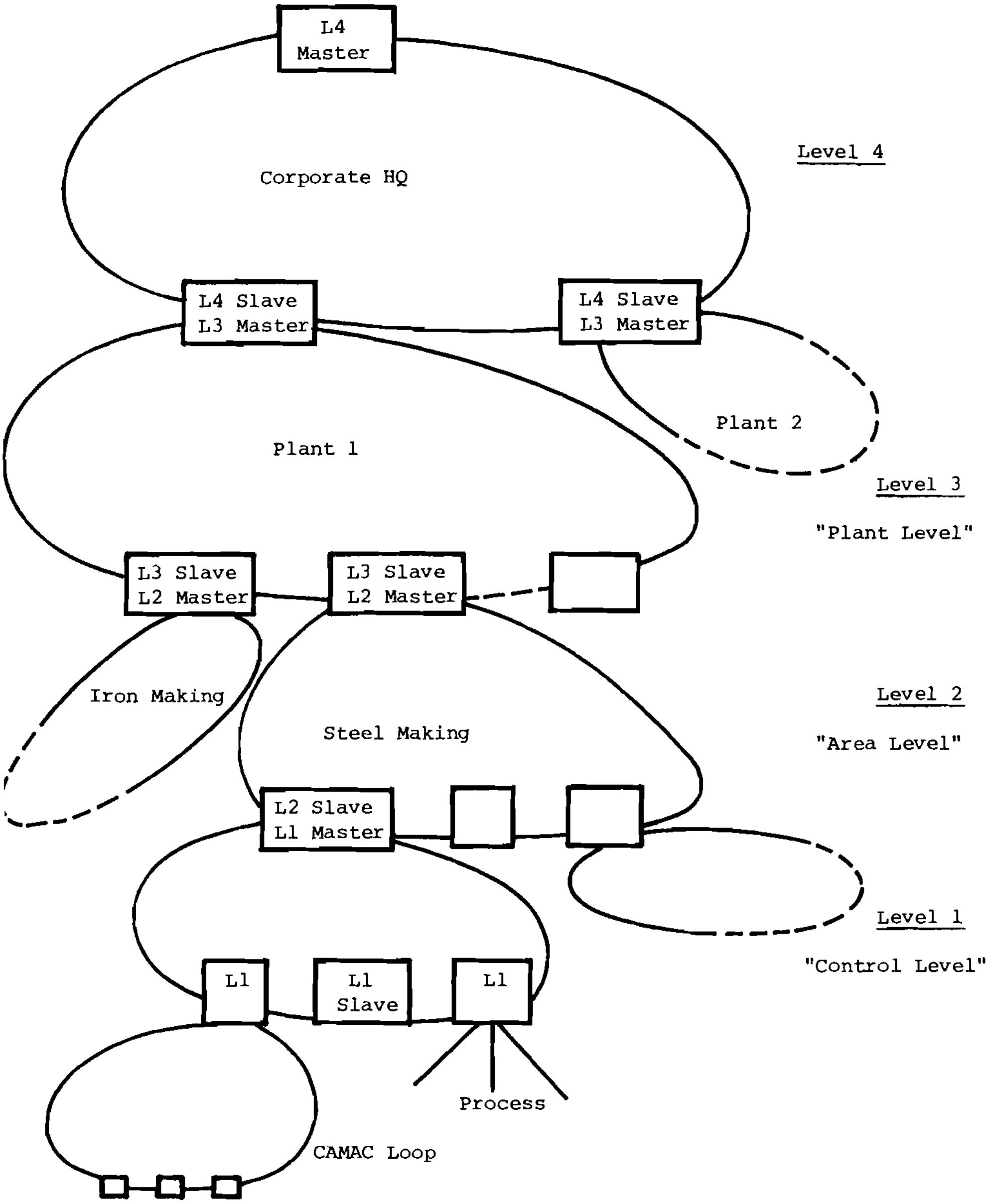
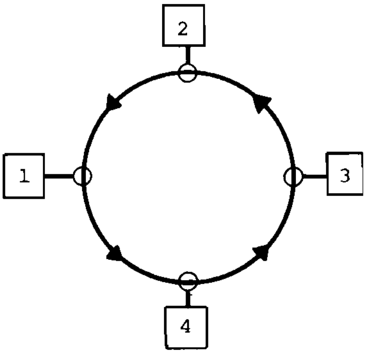


Figure 12. The multiple loop structure applied to the steel plant situation.

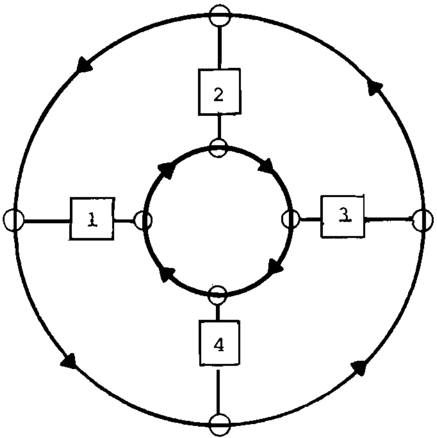
1. Unidirectional Systems

1A. Single Loop



- Simple interface processors,
- Reliability problem,
- For example CAMAC.

1B. Dual One-Directional Loops

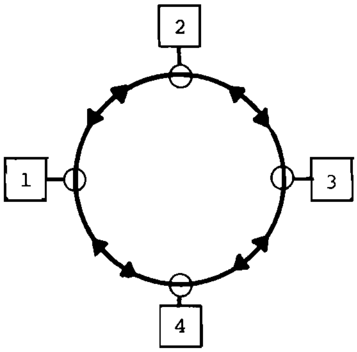


- High reliability,
- Single link failure does not affect the operation.

Figure 13. Achieving reliability by multiple paths and bidirectional operation (continued).

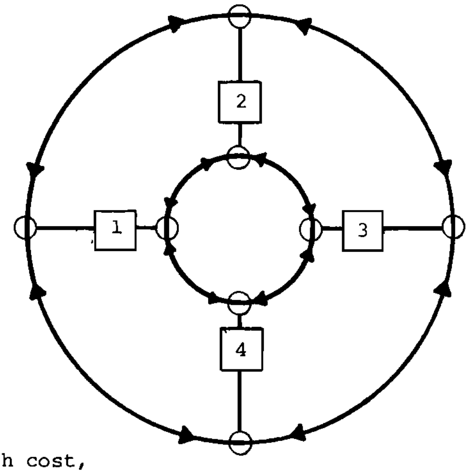
2 Bidirectional Systems

2A. Single Loop



- Slower,
- Higher reliability than unidirectional,
- More complicated network host interfacing,
- More expensive.

2B. Dual Loops



- High cost,
- High reliability.

Figure 13. Achieving reliability by multiple paths and bidirectional operation.

Table 5. Present capabilities of model used for order handling and plant scheduling studies.

Model can be manipulated by altering input of:

1. <u>Melt Capacities</u>:
   - a) Number of basic oxygen furnaces (0-6),
   - b) Number of open hearths (0-6),
   - c) Number of electric furnaces (0-2),

     Must have at least one of entire group
   - d) Capacities of furnaces,
   - e) Average heat times,
   - f) Heat degrade probabilities,
   - g) Down time probabilities.
2. <u>Process Capabilities</u>:
   - a) Process time for any or all facilities,
   - b) Probability of a miss at any and all facilities,
   - c) Number of soaking pits (1-50),
   - d) Number of hot strip mill reheat furnaces (1-4),
   - e) Rate and frequency of transport of steel from area to area,
   - f) Code to exclude caster from run.
3. <u>Customer Order Input</u>:
   - a) Orders initially not filled at simulation start,
   - b) Number of order requests per week,
   - c) Orders can be generated randomly or according to some preset mix distribution.

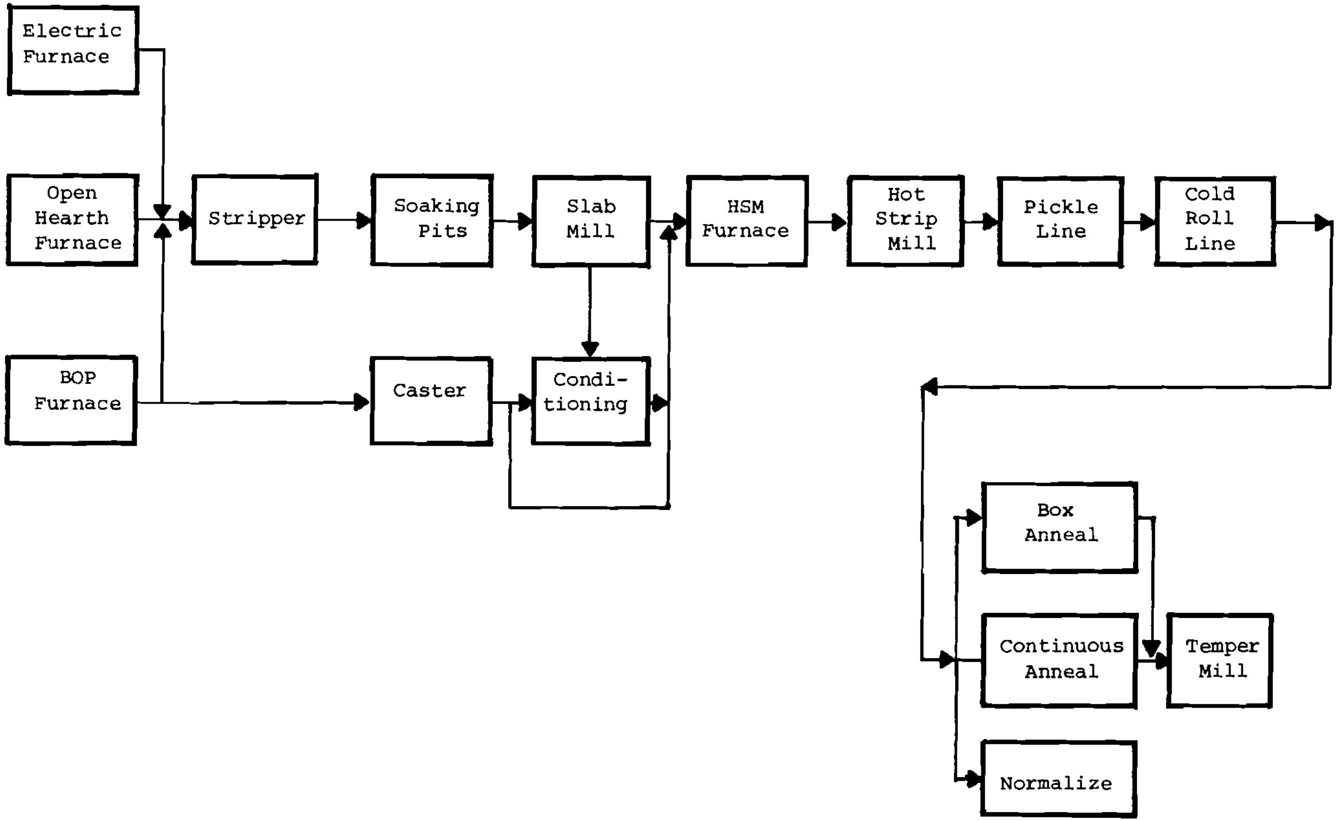


Figure 14. Portion of the basic steel mill now being modeled for order handling and plant scheduling studies.

plant outlined previously for the project. Figure 15 indicates the interfaces between processes and the pertinent control computers which are being included in the model. Table 6 outlines the currently proposed future work for this task.

An Analysis of Steel Plant Complex Operational Supervision Practices and Development of a Corresponding Hierarchical Computer Control System and its Application to Changing Company Organizations

Figure 16 outlines the plant elements being considered. Note that the sales, production planning, and process units are considered to be on-line at all times. Budget control, purchasing, accounting, and management compensation areas are considered to be off-line functions that interface only when necessary.

The Personnel of this task have developed a set of tabular techniques that not only outline the communications and command channels involved in the plant's operation but also permit the same techniques to be used for later design of the computer control system involved. These are in a set of decision tables (Figure 17), information incidence matrices (Figure 18), and precedence matrices (Figure 19). The example used for these figures is that of the basic oxygen furnace unit. The organizational chart and information flow pattern for the unit is given as Figures 20 and 21.

The decision table operates as follows. The set of questions, C_1 to C_{12}, is asked. The set of responses, R_1 to R_8, is to be answered in order as indicated before the operation can proceed. Responses are Y for Yes, N for No, S for Satisfactory, and NS for Not Satisfactory. The actions A_1 through A_{23} are then carried out in the order given in the column under each response in series. This table then outlines succinctly all operations which must be carried out by the control computer while stating their proper precedence and the factors which must be considered for intermediate monitoring.

The information incidence matrix takes the information paths of Figure 21, indicates which individual or department receives that information, (1), or sends it, (-1). It also outlines the number of transmissions involved, (MULT. TRANS.), the number of words of each, (VOLUME), and the total channel transmission, (TRANS. VOLUME). The FREQUENCY data will be added as the project proceeds.

The precedence matrix indicates the direction of message travel by the presence of a 1 in a column to indicate message travel from the vertical axis listing to that of the horizontal listing. Successive manipulation (squaring) of this matrix will pick up chain transmission of information through several individuals or groups.

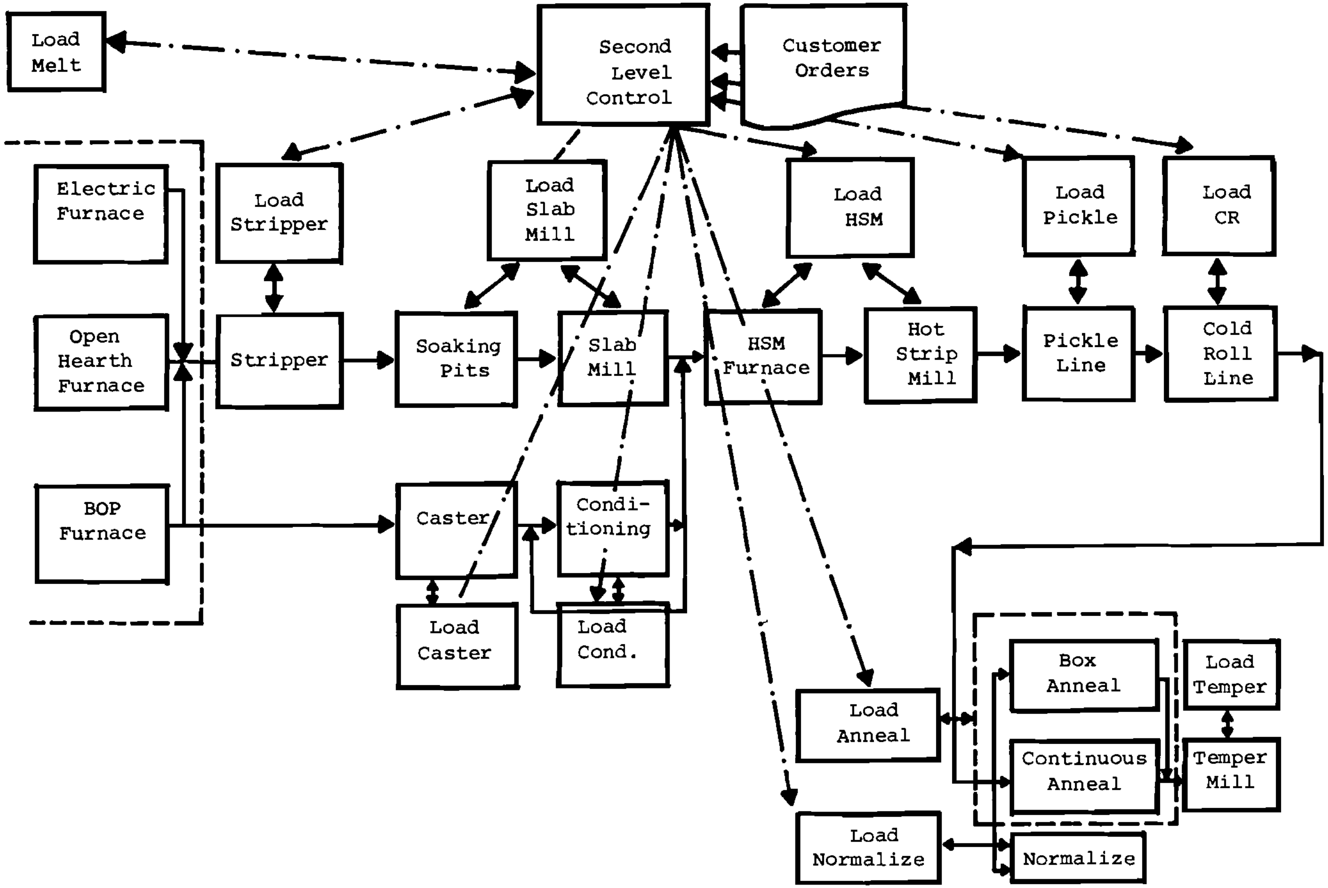


Figure 15. Interfaces between processes and control computers in order handling and production scheduling studies.

Table 6. Planned future work for order handling and production planning studies.

---

1. Extend the model to the full basic steel mill.
2. Determine the effect of customer priority logic on plant throughput and promised performance.
3. Make a scheduling strategy investigation of second level hierarchical control:
    a) Where and when to apply orders,
    b) Inventory levels (where to distribute),
    c) Scheduling of individual units.
4. Make a scheduling strategy investigation of first level hierarchical control:
    a) Collection of different types of status information,
    b) How often to communicate this data to upper levels.
5. Investigate model performance under different product mix distributions and marketing forecasts.

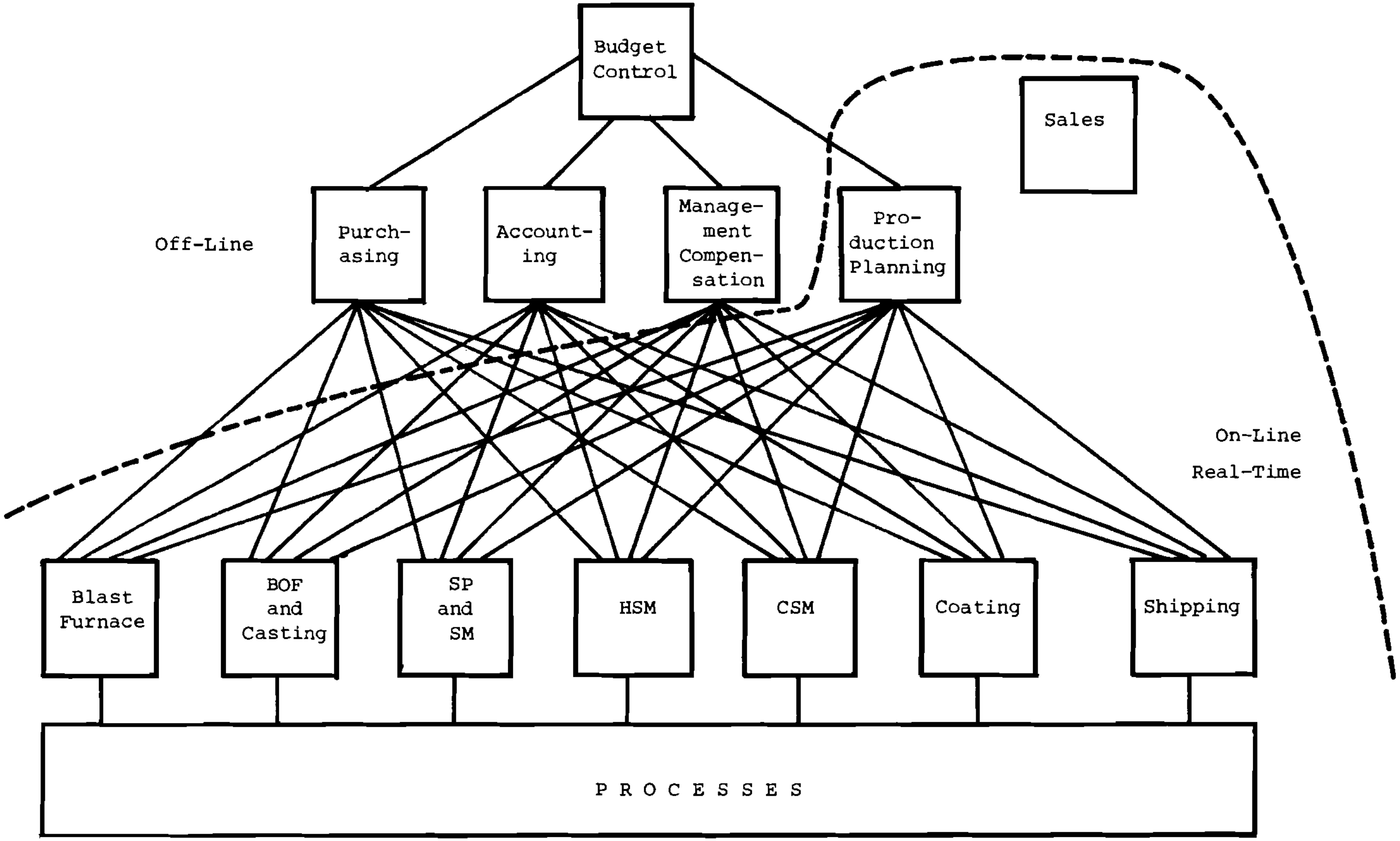


Figure 16. Outline of the plant hierarchy system as considered by task V.

		R1	R2	R3	R4	R5	R6	R7	R8
C1	Time to begin operations	Y							
C2	Vessel in position to charge	N							
C3	Vessel lining condition	S	S	NS	S	S			
C4	Hot metal ready		Y						
C5	Scrap ready				Y				
C6	Fluxes ready					Y			
C7	Vessel in position for oxygen blow					N	Y		
C8	Blowing completed						Y		
C9	Sample analysed							Y	
C10	Sample temperature								S
C11	Slag thimble ready								Y
C12	Steel ladle ready								Y
A1	Tilt vessel down	1							
A2	Calculate scrap charge		2						
A3	Prepare scrap charge		3						
A4	Charge scrap				1				
A5	Weigh hot metal charge	2							
A6	Measure hot metal temp	3							
A7	Measure hot metal sulfur content	4							
A8	Charge hot metal		1						
A9	Tilt vessel up					2			
A10	Calculate flux charge		4					3	
A11	Charge fluxes					1		4	
A12	Lower oxygen lance					3			
A13	Blow oxygen as calculated					4			
A14	Raise oxygen lance						1		
A15	Tilt vessel down						2		
A16	Take sample, send to met. lab.						3		
A17	Measure temperature						4		
A18	Calculate alloy additions							1	
A19	Add alloys							2	
A20	Consider condition C7							5	
A21	Pour off slag into slag thimble								1
A22	Pour steel into ladle								2
A23	Do not operate vessel, notify supt.			X					

Figure 17. Decision table basic oxygen furnace operating procedures.

Files

Processes	102BE	102	102H	102G	102A	102F	102C	109	103	117	122	110	112	111	121	X1	X2	X3	X4	124	123	113	120	118	X5	X6	116	X7	X8	X9	X10	X11	X12	X13	X14	105	106	107	108
Maintenance																																		1					
Scrap Prep.																																			1				
Transportation														1						-1																			
Ind. Engr.													-1																										
Metallurgical																														1	-1								
Controlling												1																											
Prod. Plan.																																1	-1						
Sales																																-1							
Purchasing																															1								
Soaking Pits																									1														
Area Supt.																	1		1	1	1																		
Supt.								1	1								1	1	-1																				
Spec. Assign.																1																							
G. Fmn. Melting															1																								
Fmn. Materials									-1	-1	1	-1	1	-1																				-1	-1				
T. Fmn. Melting			1	1	-1	1	1	-1																															
A.T. Fmn. Melting	1	-1	1	1	1	-1	1																						-1										
G. Fmn. Teeming																						1																	
Fmn. Mold Prep.											-1										-1		1	-1															
T.Fmn.Mold Prep.										1					-1								-1		-1	-1													
T.Fmn. Teeming																						-1					-1	-1	1										
Met. Obs.																														-1									
Clerk		1																-1						1		1	1						1			1	1	1	1
Recorder																												1								-1	-1	-1	-1
Barg. Group	-1	-1														-1																							
Proc. Controller			-1	-1																																			
Mult. Trans.	2	2	3	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Volume	2	23	1	1	1	4	5	100	65	84	300	1	300	90	84	1	1	1	1	330	105	154	170	200	1	1	187	1	1	10	50	200	12	1	1	50	200	150	266
Trans. Volume	4	46	3	3	2	12	10	200	130	168	600	2	600	180	168	2	2	2	2	660	210	308	340	400	2	2	374	2	2	20	100	400	24	2	2	100	400	300	532
Frequency (per min.)																																							

Figure 18. Information incidence matrix basic oxygen furnace, Armco Steel Company.

	Maintenance	Scrap. Prep.	Transportation	Indus. Engr.	Metallurgical	Controlling	Prod. Plan.	Sales	Purchasing	Soaking Pits	Area Supt.	Supt.	Spec. Assign.	G. Fmn. Melting	Fmn. Materials	T. Fmn. Melting	A. T. Fmn. Melting	G. Fmn. Teeming	Fmn. Mold Prep.	T. Fmn. Mold Prep.	T. Fmn. Teeming	Met. Obs.	Clerk	Recorder	Barg. Group	Process Control
Maintenance																										
Scrap Prep.																										
Transportation											1				1											
Indus. Engr.															1											
Metallurgical																	1									
Controlling											1	1														
Prod. Plan.																							1			
Sales							1																			
Purchasing																										
Soaking Pits																										
Area Supt.																										
Supt.											1															
Spec. Assign.																										
G. Fmn. Melting																										
Fmn. Materials	1	1				1			1			1					1			1			1			
T. Fmn. Melting												1					1									
A. T. Fmn. Melting			1													1					1		1			
G. Fmn. Teeming																										
Fmn. Mold Prep.											1				1								1			
T. Fmn. Mold Prep.										1				1					1				1			
T. Fmn. Teeming																		1					1	1		
Met. Obs.					1																					
Clerk																										
Recorder																										
Barg. Group													1				1									
Process Controller																1	1									

Figure 19. Precedence matrix basic oxygen furnace, Armco Steel Company.

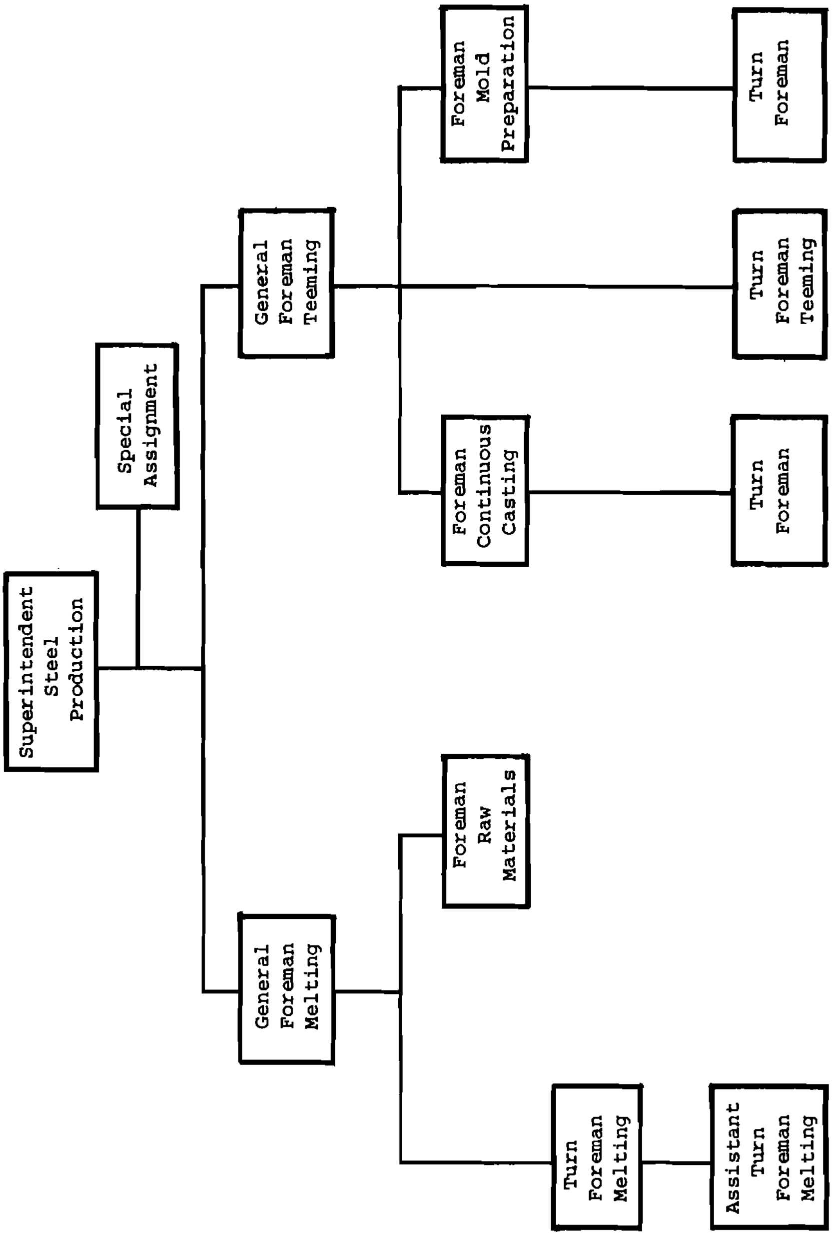


Figure 20. Organizational chart, basic oxygen furnace.

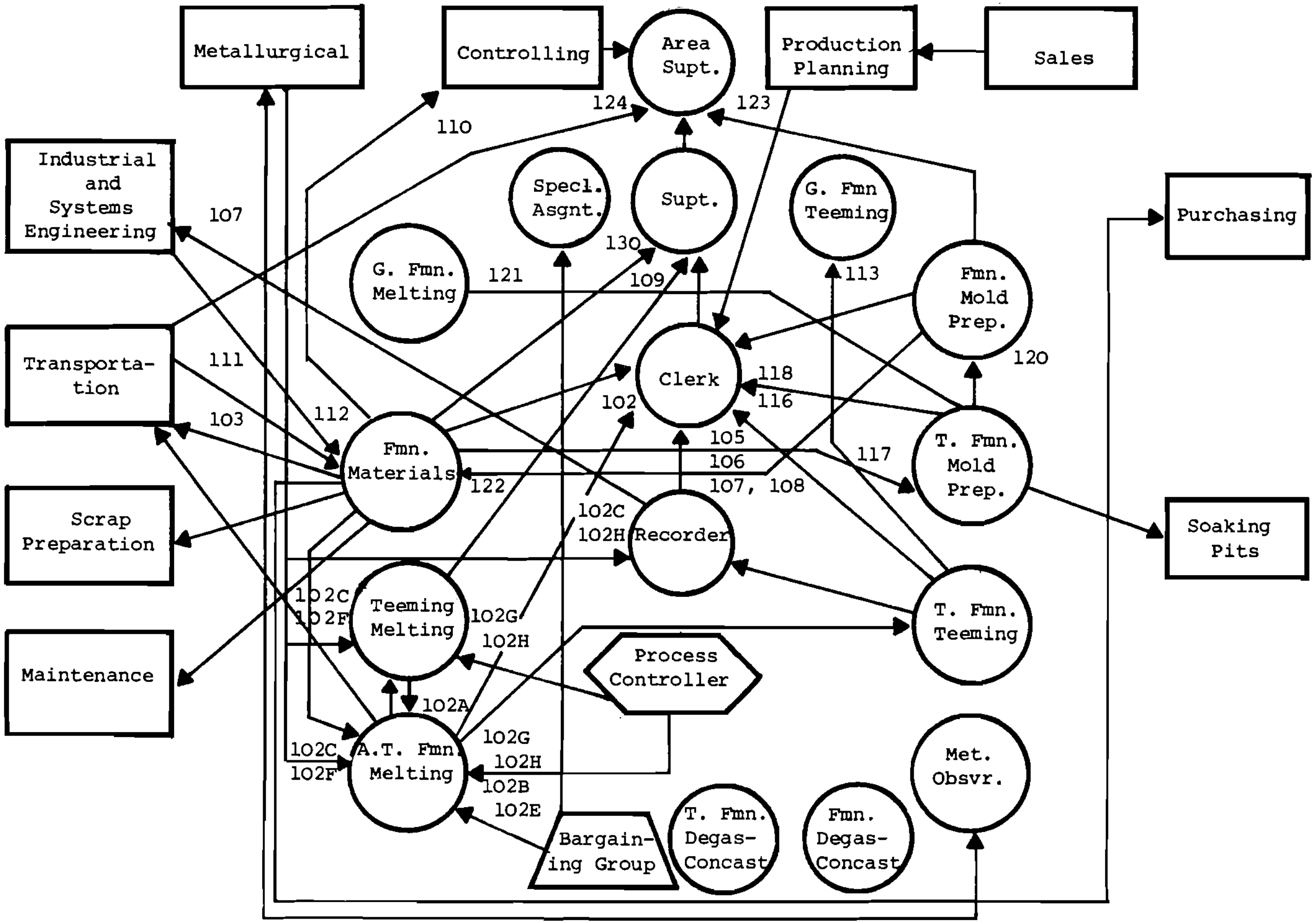


Figure 21. Information flow chart, basic oxygen furnace.

As stated previously, these techniques will be extremely helpful in our later design of the computer control system for the plant.

Analysis of Reliability Requirements of Steel Industry Hierarchical Control Systems and Specification of any Needed Developments

Figures 22 and 23 diagram the types of systems that have been analyzed by this research team to prove the applicability of the GRASP I Simulation Technique that was especially developed to help solve these types of problems. They are now in the process of collecting the data types of Table 7 to continue their work on actual steel industry examples.

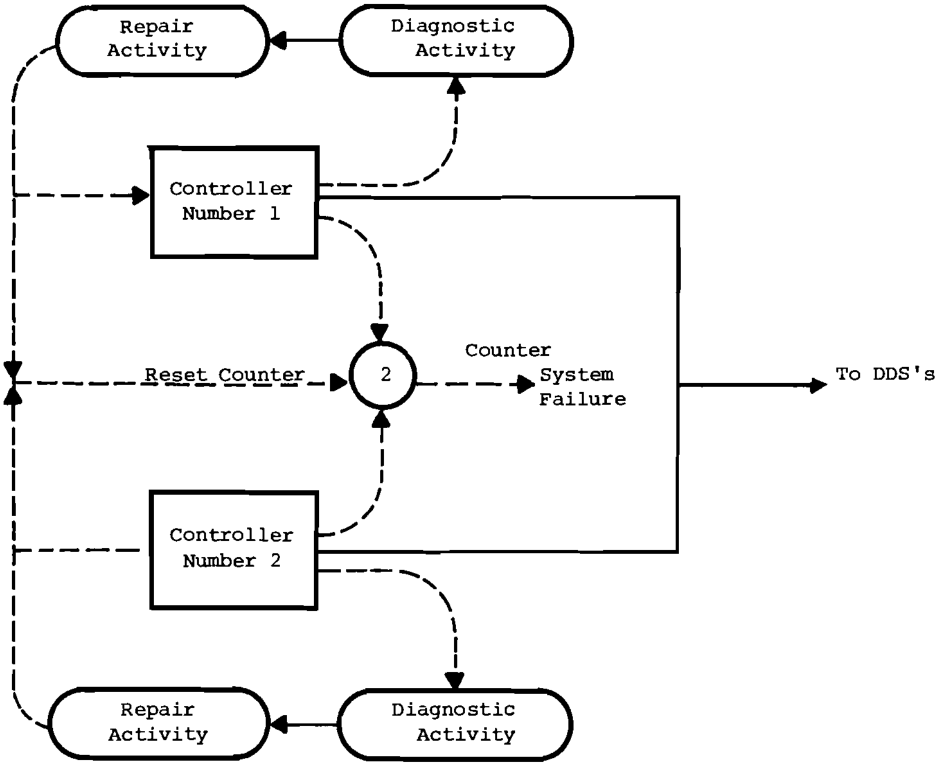


Figure 22. An assumed model of a supervisory controller with redundancy.

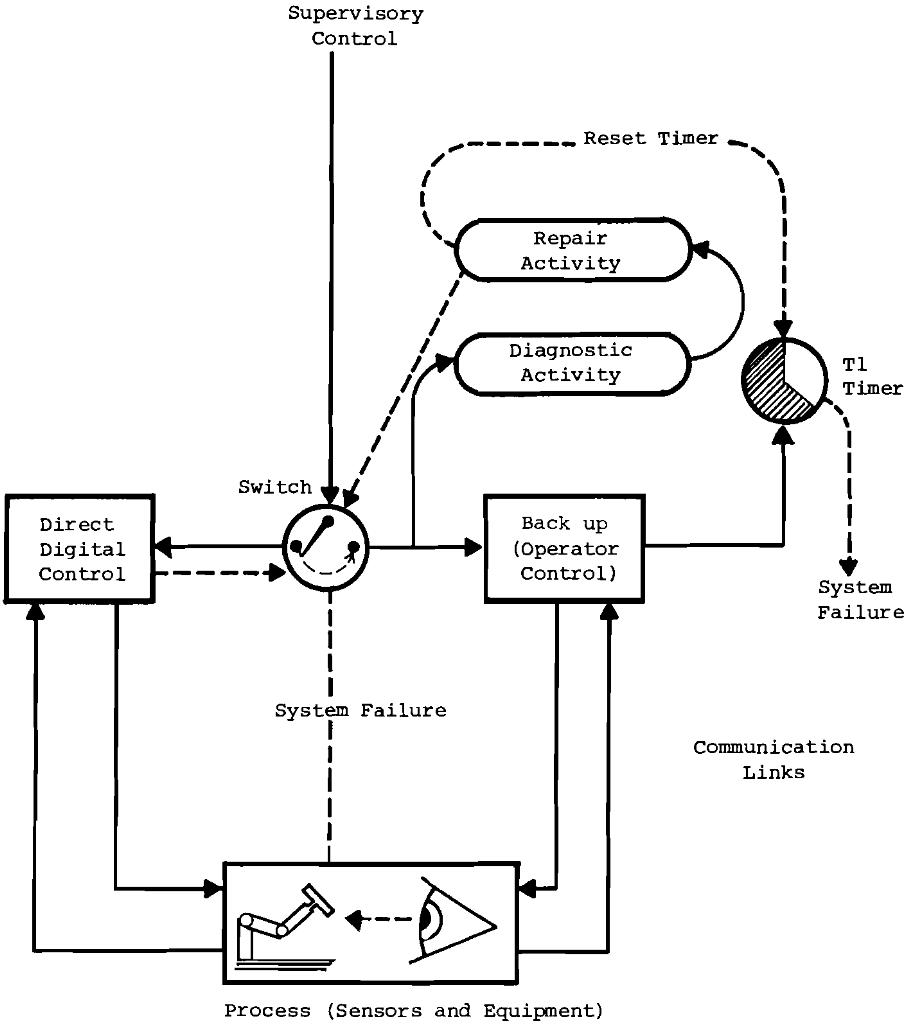


Figure 23. Reliability model of a typical subsystem.

Table 7. Desirable data to be collected for reliability analysis studies.

---

1. Time of failure.
2. Type of failure (hardware, software, etc.).
3. Level of failure (supervisory, DDC, etc.).
4. Time that cause of failure is identified.
5. Identification of component/condition causing failure.
6. Description of repair activity.
7. Time repair completed.
8. Repair successful? If no, repeat lines 4-8.
9. Time normal service resumed.

References

Dallimonti, Renzo (1973), New Designs for Process Control Consoles, *Instrumentation Technology,* 20, 11, 48-53.

Halverstadt, D.A., D.H. Kern, and T.J. Williams (1974), *A Plan for the Automation of the DE 1052 Class of Naval Surface Ships,* Report No. 61, Purdue Laboratory for Applied Industrial Control, Purdue University, West Lafayette, Indiana.

Nuclear Instrument Module Committee, US Atomic Energy Commission (1972), *CAMAC, Organization of Multi-Crate Systems,* Report TID-25876, National Bureau of Standards, Washington, D.C.

Nuclear Instrument Module Committee, US Atomic Energy Commission (1972), *CAMAC, A Modular Instrumentation System for Data Handling,* Report TID-25175, National Bureau of Standards, Washington, D.C.

Nuclear Instrument Module Committee, US Atomic Energy Commission (1973), *Revised Proposal for Organization of Multi-Crate Serial CAMAC Systems,* NDWG-73-4, National Bureau of Standards, Washington, D.C.

International Business Machines Corporation, *Synchronous Data Link Control, General Information,* White Plains, N.Y.

T.J. Williams, ed. (1971), *Interfaces with the Process Control Computer-The Operator, Engineer, and Management*, Instrument Society of America, Pittsburgh, Pennsylvania.

Discussion

Lefkowitz

I have a general question with respect to the information chart that you showed near the end. I assume that it represents what currently exists in the system. Has there been any effort to look at the problem from the standpoint of what actually has been needed by the different people in this chain?

Williams

The information that is there, of course, refers to the current situation in the minds of the people interviewed. We have not yet modified this in terms of any new control situation. This has to be done and, yes, we will certainly try.

Kopetz

Were your overall concepts very highly influenced by the hardware technology that is currently available.

Williams

Yes.

Kopetz

Are you also looking for new developments on the software side and how they might influence the structure, for example, the development of distributive data bases?

Williams

Well, I think we are actually using distributive data bases in terms of the fact that essentially we do have all these systems on file. I guess that is what I would call distributive data bases, and I think that is what you are talking about. Now, we have not looked at packet switching. We think, at the present time, that we would do this in terms of continuous transmission of the information as needed. I guess I do not see any reason why packet switching would not work, at least going up the hierarchy. Now I have some doubts in my mind about packet switching going down, but there is certainly no problem about packet switching going up, in my mind at least.

Cheliustkin

You mentioned that you have divided the problems into the different regions: blast furnace, steel making, and metal rolling.' Why do you not include the teeming and casting operations in steel making; they are very much tied together in scheduling. You have to consider the capacities of not only the steel making facilities but also the continuous casting and teeming facilities, and so on.

Williams

Well, because we have separate computer systems in the two areas, does not say, of course, that there is not close coordination between them.

Cheliustkin

Now I want to ask a second question, and it concerns the data base that you used in this system for planning, scheduling, and production control. The controls should be based on different information sets depending on the relative time scales for the scheduling and planning functions.

Williams

The system we are talking about is involved in scheduling but not in the planning operation.

Cheliustkin

Also, associated with different time scales?

Williams

Oh, yes, there would be a different time scale involved, for example, in the overall production control computer and in the local computers supervising each of the areas. In fact, what we conceive is that the overall production control system would carry out the main schedule and transmit to the area computers the schedules that they should follow as needed, essentially perhaps, on a shift by shift basis.

Cheliustkin

Concerning the reliability of the system, you have considered only the reliability of the process control system but not the system as a whole.

Williams

We feel that the reliability of the production system is not our problem, and that, as far as the control system is concerned, it must not fail and it must not be the cause of any failure of the total system. Even though the control system may be more reliable than the production unit, you cannot take advantage of that, in terms of designing the total system because it is not acceptable. It just cannot fail or at least not fail in a short period of time.

Kovacs

How do you share the research work implementation between industry and the university?

Williams

We are not involved in implementation. As I have mentioned, our output is essentially a specification of the kind of a system we would view as necessary. The companies are supplying us with the data that exist at the present time, or are providing the capability for our students to collect the data they need. They are also helping us in the analysis of the problem, and they are reviewing, almost continuously, the results our people achieve.

Kovacs

And the actual programming is done in the factories?

Williams

If there were implementation of this system at the moment, we would assume this is being done by the companies, the implementors. That is not our job. Now, we are doing a lot of programming, but at the moment it is simulation type programming.

de Gregorio

I have two points. First, with this integration of the system, is it possible to introduce state estimation, in other words, to make the system congruent on the models? In the electrical industry, this is already being done.

Williams

Yes, we think that what to do would be to use--and I think that is what you are saying--on-line models which would develop essentially the concurrent simulation, the values of the variables we could not otherwise measure.

de Gregorio

The second question is related to the use of standby computers. When one computer is wrong, do you switch over, for example, during repairs or do you use just one channel?

Williams

Is what we are talking about a single redundant computer, or two computers?

de Gregorio

Two computers.

Williams

Doing identical jobs--one of which is active and both computers continually test one other?

de Gregorio

Yes, when one if failing, you lose your ....

Williams

Yes, of course.

de Gregorio

Since computer hardware is somewhat standardized, is it possible to envision some other system configuration? For example, would it be conceivable during repairs to have a few computers, say 5% or so, that are used as general standbys?

Williams

The problem with that kind of system, of course, is that you do not know which job the standby computer must pick up. The programming of the system would have to allow it to do pick up tasks unknown at present; I think it would be extremely difficult. Therefore, we do not want to try that. We think that the systems are good enough, based on the fact that the failure rate of these systems is very, very low at the moment, and there should be plenty of time to repair the second computer while the other one is running.

Kopetz

How do you cope with software failures in these systems?

Williams

What we assume we can do is have a test problem that will be run during idle time of the system. Any time that this test problem fails, or any time that the systems, in checking each other, detect an error, we immediately fail the machine that gives the error. Do not ask questions, just fail it and then check it later.

We assume that the software is checked and, therefore, there are no major errors in it. Intermittent faults in incremental control systems are no problem, so I do not think that your software failure is going to be a problem, unless there is a major fault, and I think we can check that in the implementation.

Cheliustkin

In the simulation of the processes, you have used various standards. For instance, if you are simulating the continuous casting machine operations, you have to know the time needed for the casting of different sizes of slabs. If you simulate the rolling mills, you have to know the duration of the rolling cycle and so on. Have you investigated whether the standards used in current practice are really good for control? Sometimes, the standards used for the scheduling have built-in allowances to guarantee schedule achievement. So, have you investigated the standards that you are using for the scheduling and what you have used for the simulation?

Williams

You mention standards, but we are not really using industry standards in our simulations. The data we are actually using are data that students got from a particular plant for the simulation of the production control. If, in terms of that particular data, we get these overlaps you are talking about, they do show up in the simulation. Now, if our data are incorrect, in terms of the averages of the industry, we will not get the same overlaps that you are talking about.

Cheliustkin

But there is a dispersion of the data and we have to consider it.

Williams

Oh, I understand. We are assuming that the data we have are good enough at the moment. Now it will be checked, of course, before we are done. Now if they are not as good as the data you are talking about, then we will not get the same answers that you have, but, as I said before, we assume these data, that come from the experiences of one of the companies, are good enough.

Cheliustkin

I think that these standards or data probably can be improved after implementation of the process computer control, since, by means of the computer control system, the dispersion of data will tend to be reduced.

Williams

In terms of what the computer control will do to these data, we do not know.

Lefkowitz

Getting back to the reliability question, do you detect any change in industry's attitude regarding computer system reliability requirements? We have gotten inputs from some sources that say there has been a detectable shift away from thinking that the computer system had to be 99.99% reliable. They are looking at computers more and more in the same sense that they look at any other major equipment--when it fails, you shut down and repair it and then start up again.

Williams

I guess I think it depends upon whom you are talking to and in what context. If I am talking to you about his computer then, no, you do not need it. If I am talking to you about your computer then, yes, you do need it. So, I think that, as far as what we are proposing, we have a super redundancy and super reliability designed into the system.

Marguiles

You unfortunately left out the chapter on man-machine interface in your presentation.

Williams

As you yourself said, the paper is too long to present in one hour.

Marguiles

Did you investigate social science problems like job satisfaction at all?

Williams

We have been a little short-sighted here, I think, in terms of assuming that the job satisfaction problem is external to the scope of our study and something that somebody else would have to tackle. We have felt that if we solve the man-machine problem, then at least we will have made our contribution to the satisfaction problem.

Marguiles

But you will keep it open for somebody else?

Williams

Of course. We have just a few people and to tackle that problem too, on top of everything else, would be far too much.

Kelley

We seem to be accepting the notion that minicomputers are the way to tackle the sort of problem we have been covering. Can you tell me whether the argument for minicomputers as opposed to a larger computer covering a wider area is purely on reliability grounds or are there other factors that have led you to the present result?

Williams

I think that we have learned, to our horror, about the problems of programming big centralized systems, and that is the reason why we feel that we have distributed the tasks.

Kelley

But you are trading, then, the difficulty of programming this very complex network of interlocks and tests and so on, and it is no mean problem.

Williams

No, but I think it is unusual.

Kelley

So reliability is not on the top of the list?

Williams

Well, I guess I assume that I can achieve reliability by means of redundancy and error checking between the systems at reasonable cost. You and I and many other people have been through the problem of programming the centralized system, and I do not want to tackle it again, not in a system so big as this.

On Some Experiences with Production and Process Control in the Steel Industry

M. Knotek

In my report I will try to explain the experiences of the INORGA Institute with a view of development of computer scheduling production and control systems. As mentioned by I. Lefkowitz, INORGA is an institute for industrial management and automation in the CSSR. Let me give a short presentation paper. I shall begin with some of the history of INORGA.

People in the INORGA Institute have been engaged in the steel making industrial production control field for about 15 years now. Originally, the effort was oriented toward application of methods of mathematical statistics, mainly statistical interpretation of steel properties, quality control, experimental design and analysis, correlation, etc. In 1960, we began work on the application of operational research techniques (such as simulation and mathematical programming) and we were one of the first research centers in the CSSR to use computers as a tool for research. In 1964, we approached the design of computerized production control systems for the first time. The experience gained from the different production control systems has been generalized since 1970 to solve selected methodological and/or theoretical problems.

Our conception of the scheduling and production control area is very similar to that described in the draft review and presented yesterday by D. Kelley and A. Cheliustkin. We have experience with four areas of scheduling and production control: capacity loading and production scheduling, production operational control, production reporting and process control.

We still do not solve problems for the business strategy level, and for the long and medium-term planning levels. We have some relatively small experiences with the one-year planning level. Our main attention, therefore, is on the scheduling, production control, and process control levels. Regarding the use of mathematical methods for the solution of these problems, we think that they may be applied in the following program: 1) identification of the control object, 2) definition of system requirements, system concept and design, 3) development of the decision-making algorithms, and 4) performance analysis and utility. It seemed to us that the first three phases must be particularly stressed and developed, both theoretically and methodologically. The use of the mathematical methods in these application areas has not been fully appreciated so far.

For the development of decision-making algorithms, advanced mathematical techniques can be applied. Although, for some of them, mathematical programming has been developed for complete projects, for instance, in our institute and in my country, the implementation was not carried out and less exact methods were applied. The reason for this was that these simpler methods were based on a heuristic approach model that actually worked better. Methods for performance analysis and utility have also been developed in the last few years in our institute and in other places in Europe, so there has been a lot of practical experience with their use. Hence, they may play an important role in the methodology for development of production control systems.

We have had good results in the development phases through the application of simulation methods that were mentioned in this Conference. The dramatic development of computer hardware and software in recent years provides a good base for implementation of complicated integrated production control systems. It seemed to us that computer scheduling and production control systems in industry will be influenced, by two typical factors for a long time. First, process mechanisms and control decision-making rules are not specified to a sufficient extent. Second, production changes and organization show a considerable degree of dynamics. Consequently, we believe that even in the next development it will be necessary to consider the man-machine system as the most important part. From this it follows that the development of mathematical tools and both hardware and software facilities must be geared to this tendency.

Now let me say a few words about the development of the education of computer control systems in the steel industry. The CSSR approach to designing a computer control system in the steel industry corresponds basically to the history of the European development. An analysis of the development of the CSSR steel industry shows approximately a three-stage design approach. First, we have the integrated concepts of computer production control systems with a large number of automated control functions. Second, there is development of individual isolated automated function areas for different production control problems. Third is the production control system based on the common data bank.

The production control system for the soaking pits and the rolling mill area in the NHKG Ostrava works have been typically representative of the first group of systems. This system was built initially during the years 1965 to 1973. The system has been designed and algorithmically prepared in a very solid way, but in spite of considerable efforts, it was not made operational to the original extent planned owing to a number of factors, including the lack of sufficient software, inadequate hardware processing facilities, and also unsatisfactory experience with systems people in the design of such complicated integrated systems. The system was redesigned; it now works quite well and gives good results.

The second group of systems, that is, based on individual isolated automated function areas, may be illustrated by the development of the Kosice control system. The first stage of the LD convertor process control system was developed through a data logging and production monitoring system. The second stage was developed through an operation control system at the steel plant level: the slabbing mill area was implemented using another computer. These systems worked independently, and got very good results. Representatives of the Kosice steelworks, Messrs. Jelinek and Kyselowic, are here, and if you have some questions I think they will be prepared to answer you.

An example of the third systems design approach, that is based on the data bank, is the information production control system for CSSR iron and steel production at the SONP Kladno works. This system was built during 1969 to 1974, after we already had some experience with production control system development in other CSSR steelworks. The system includes the following functions: order entry, order processing, production reporting in the steel plant, production reporting in the order area, ingots and semifinished products, inspection, and weighing.

Relatively independent development in the design of individual functions provides the capability for gradual implementation and for introducing revisions in the system concept. System elements are expressed in the data base design in a way that provides standard information on the execution of different system functions. Also the organization of other files in the data base is rendered possible by multiple inputs of stored data.

The INORGA Institute participates to a considerable extent in the developments at the Ostrava and the Kladno works. In the methodological area, a number of research projects have been undertaken and many reports have been published. The common goal was to prevent the repetition of the most frequent errors and to propose efficient procedures for production control systems, for instance, a joint method of research work in this area was worked out by INORGA and CNIIKA, the Central Research Institute of Complex Automation in Moscow. This report was published in Prague and Moscow. Important parts of this methodology were worked out jointly in detail.

Since 1969, INORGA has been engaged in research in mathematical models for production scheduling. The first efforts were devoted to problem definition, verification, and interpretation of properties of basic types of models including stochastic and heuristic simulation models, and development of selected scheduling models and their algorithms.

Simultaneous with the development of the algorithmic models, their testing for actual application was carried out. Based on this practical experience, we tried next to develop models and algorithms for scheduling problems of more realistic size, without introducing any principle restrictive assumptions. These requirements are met, in our opinion, by means of heuristic algorithms which enable man-machine interaction during the scheduling process. The models and algorithms are developed using both deductive and inductive principles. Depending on the type of production, an effort is undertaken to build a "catalogue library" of scheduling algorithms in a systematic way.

The INORGA Institute also has been engaged for some time in the development of mathematical tools for direct operations (or production) control. Also, in this area are investigations of various heuristic approaches. Our institute traditionally has paid high attention to the application of Monte Carlo simulations for the solution of production control problems. At the beginning of our effort in this field there were occasional case studies based on the use of GPSS and SIMULA languages. At the moment, we are engaged in the development of a generalized simulation model for the rolling mill area. Some attention is being paid also to the verification and validation of simulation models and simulation experiments in design analysis.

Methodological and theoretical problems investigated in the INORGA Institute regularly become topics of periodical national or international seminars. Every three years, we organize an international seminar under IFORS sponsorship for production control and scheduling algorithms. The next seminar will be held in 1976. I plan to deliver the present paper on production and process control at the 1976 seminar.

In the future, we also shall have to investigate methodological and theoretical problems of special structure regarding production scheduling, production control, and simulation models. Practically, we shall continue in such a way as is described in my report. Of course, we would also like to develop and standardize project solutions for integrated control systems in certain production areas, namely, the soaking pit area. This was mentioned by A. Cheliustkin who showed the importance of this area for the steel plant. We fully agreed with his argument, and, therefore, we started work on a solution for this problem.

The people of INORGA welcome IIASA efforts in the field of production control for steelworks on an international scale and we consider this to be a pioneering effort. Certainly, it would be useful to exploit this effort to prognosticate future developments and, from this, derive worthwhile thematic subjects for projects in methodological, systems analysis, modeling, and algorithmical research areas, as well as in the development of both hardware and software facilities to provide effective backup for even the most challenging projects.

An Example of a Schedule Model in An Integrated Control System

G. Surguchev

The general concepts of integrated systems control in the steel industry have been formulated in the Integrated Industrial Systems Project's the State-of-the-Art Survey and presented at the Conference. In our activities we tried to make certain contributions to the solution of some concrete tasks.

Here we speak about the scheduling problem for steel complexes. As an example, we consider an industrial system consisting of two complexes, basic oxygen furnaces (BOF), and continuous casting machines (CC) for steel production. Such systems are considered to be effective and are being installed all over the world. According to a number of forecasts, steel production will be based mainly on these processes in the near future.

The task of the oxygen-converter complex is the production of steel of a given composition and temperature. Cyclic production is characteristic of these complexes. On the other hand, the task of the continuous casting machine complex is the continuous casting of steel in slabs of given dimensions.

When scheduling the mutual work of BOF and CC, there is the problem of choosing the schedules for which overall productivity is maximal. In other words, the frequency of preparation of heats in the oxygen-converter complex should correspond to the productivity of the continuous casting machine complex.

In accordance with the given steel grade, the productivity possibilities of each complex, energy requirements, and other conditions are changed. In this case the problem of operation-state scheduling arises. Our example has been developed through collaboration between myself and I. Zimin of IIASA, and the results have been formulated and published.[1]

In a melting and continuous casting process that we consider, every job consists of the three tasks: melting, preparing for casting, and casting itself. We consider the problem

---

[1] See Igor Zimin and German Surguchev (1975), "Short-Term Planning of An Integrated Industrial Complex", RM-75-13, IIASA Laxenburg, Austria.

described by the following conditions:

1) A set of S jobs must be performed. The j-th job consists of n_j tasks numbered from 1 to n_j. The maximal time to perform each task is a known integer represented by T_{ij} for the i-th task of the j-th job.

2) A set of K different resources is available. R_k is the amount of the k-th resource available in any time. The amount of the k-th resource required by the task ij during its processing is r_{ij}^k. For example, the resources correspond to the machines of a job shop, and each task requires only a single machine during the interval of its processing.

3) No preemption of task performance is allowed. Once the task ij is started, it must be processed until completed in no longer than T_{ij} time units and no less than T_{ij} time units.

4) The start times of the tasks on a given job are constrained by a cycle-free network of the CPM-PERT type (see Figure 1).

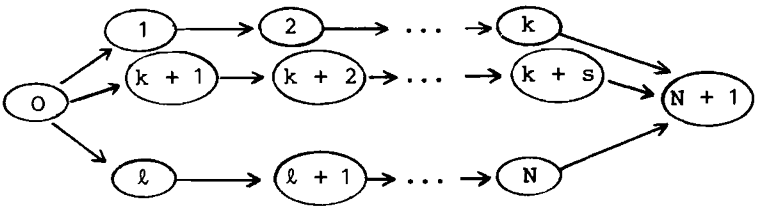


Figure 1.

5) We are required to find the values for t_{ij}^o (start time), $j = 1,\ldots,n_i$, $i = 1,\ldots,S$ that satisfy conditions 1) to 5) and for which the total number of jobs (or tasks) completed during a given period of planning T is maximal.

The "dual" problem of minimizing the completion time of a given set of jobs can also be stated.

The network diagram of the tasks is shown in Figure 2.

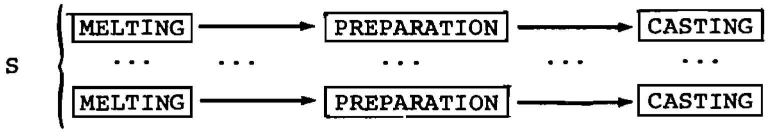


Figure 2.

The number of converters for melting and the numbers of casting machines for casting are considered here as resources. We formulate the model by using a single index:

Dynamic equations in a finite-difference form:

$$x^{3k-2}(t+1) = x^{3k-2}(t) + u^{3k-2}(t) \qquad \text{(melting)},$$

$$x^{3k-1}(t+1) = x^{3k-1}(t) + u^{3k-1}(t) \cdot \theta\,(x^{3k-2} - 1)$$

(preparation),

$$x^{3k}(t+1) = x^{3k}(t) + u^{3k}(t) \cdot \theta\,(x^{3k-1} - 1)$$

(casting),

$k = 1,2,\ldots,S$, and

Resource constraints:

$$\sum_{k=1}^{S} a_k\, u^{3k-2}(t) \leq m, \quad \text{(the number of converters)},$$

$$\sum_{k=1}^{S} b_k\, u^{3k}(t) \leq n, \quad \text{(the number of continuous casting machines)}$$

where

$x^{ij}(t)$ = portion of the ij-th task performed by the time t. It could be interpreted as a portion of the total time (T_{ij}) required for performance of the task by time t;

$u^{ij}(t)$ = performance intensity or portion of the ij-th task having been completed within the period $[t - 1, t]$;

$$\theta(y) = \begin{cases} 0, & \text{if } y < 0 ; \\ 1, & \text{if } y \geq 0 ; \end{cases}$$

a_k = time required to complete the $(3k - 2)$-th melting;

b_k = time required to complete the 3k-th casting;

c_k = time required to complete the $(3k - 1)$-th preparation for the 3k-th casting.

When introducing the multiplier θ to the right-hand side of the equations, we take into account the precedent relations formulated in the point 4). The objective function is

$$I(u) = T$$

where T is the time of completion of all the jobs.

The algorithm that has been used for solving this problem is based on the successive approximation method and on some standard procedures (simplex method). Each calculation in our numerical example requires about 0.1 seconds of computer time on the CDC-6600 computer.

We have done some computational experiments with the model presented. The network diagram is given in Figure 3 for the case S = 5. The results are shown in Figures 4 and 5.

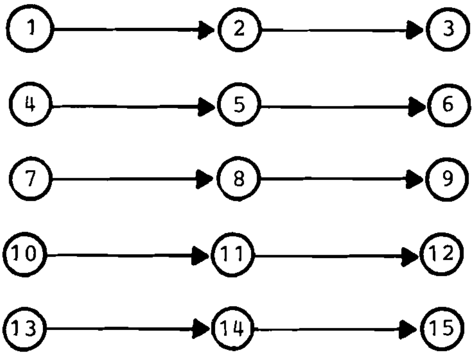


Figure 3.

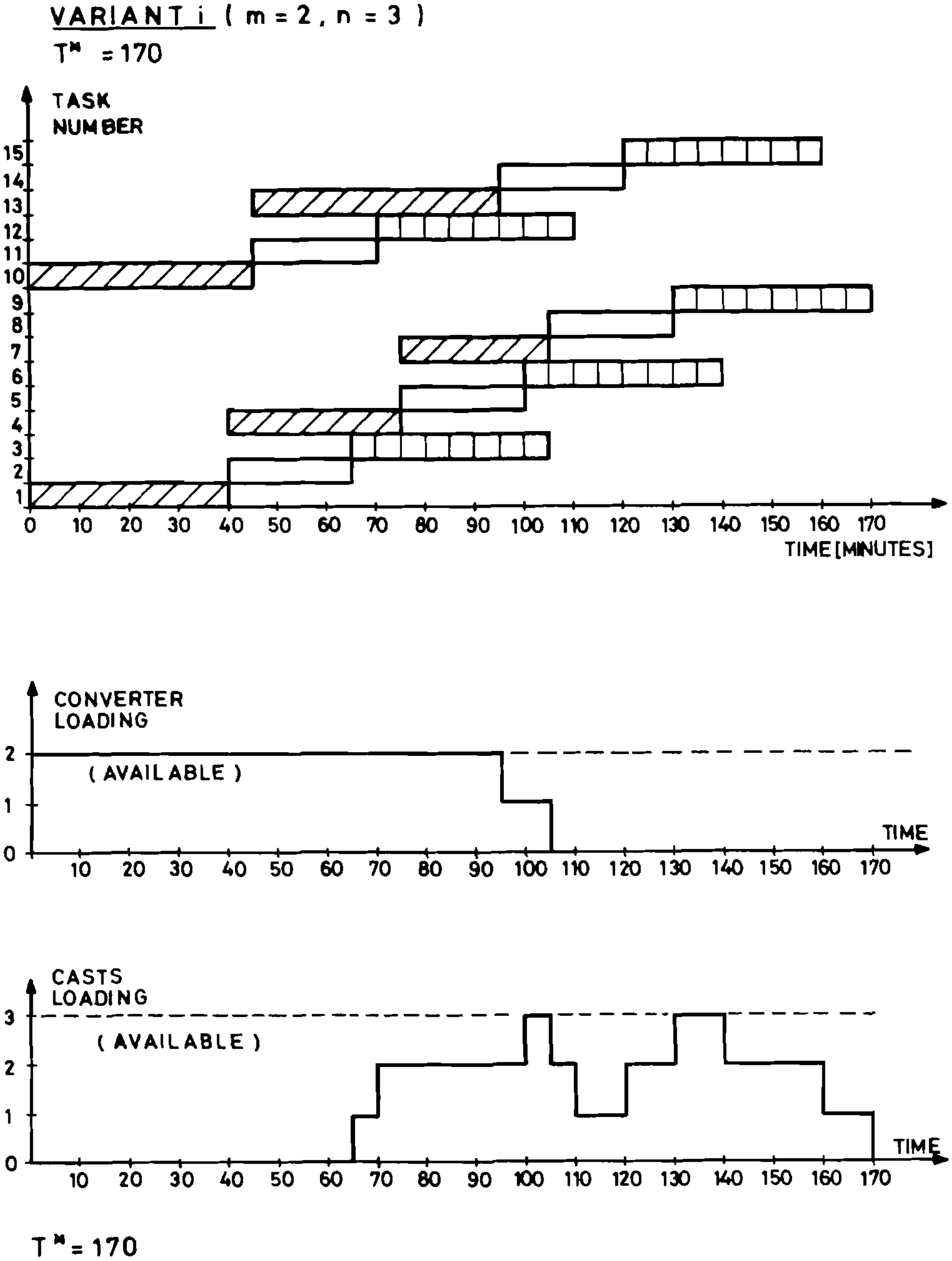

VARIANT i (m = 2 , n = 3)
T* = 170
TASK NUMBER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
TIME [MINUTES]
CONVERTER LOADING
2
1
0
(AVAILABLE)
TIME
CASTS LOADING
3
2
1
0
(AVAILABLE)
TIME
T* = 170

Figure 4.

VARIANT iii (m = 4, n = 4)

$T^{*} = 140$

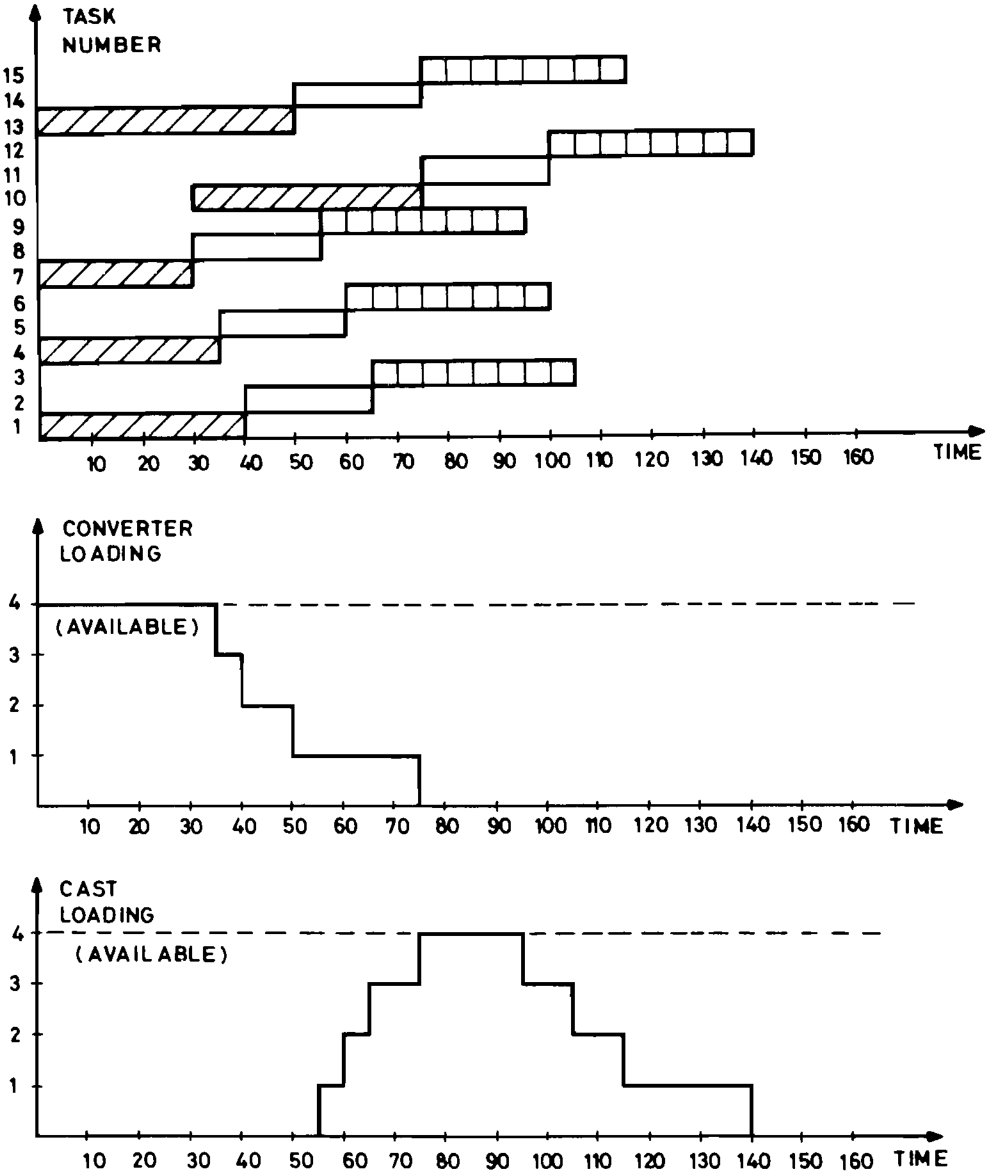


Figure 5.

Thus, tasks 1, 4, 7, 10, 13 correspond to the meltings; tasks 2, 5, 8, 11, 14 are preparations for the castings; and tasks 3, 6, 9, 12, 15 correspond to the castings.

Ghant diagrams that correspond to the optimal solution of the problem and resource loading are shown in Figures 4 and 5 for different resources available (m and n). The construction of the surface T^* (m, n) would help the management of a plant or a job shop to select the appropriate amount of facilities from the available set and to deal with the input-payoff analysis very effectively.

Discussion

Lefkowitz

I would like to ask a question that relates to the previous speaker also. In effect, Williams described the problems of production scheduling, process control, and organization in an environment that is dominated by private industry and, of course, your INORGA institute is concerned with steel making in a planned economy. Do you have any comments with respect to similarities and differences in terms of objectives, criteria, or other factors relevant to the problems of control and integration?

Knotek

I think there must be many similarities in the objectives of the socialist and non-socialist countries in production control and scheduling in steel making. I am sure that in this there was an interesting approach by Williams, but I am afraid that there would be trouble with its implementation. According to our experiences, a steel plant has rules that are used only for this steel plant and the people who know this steel plant's methods. I think these people must feel that it is the project of these people of the steel plant. They must cooperate with you.

Lefkowitz

My question was prompted somewhat by my own experiences in visiting steel plants in the Soviet Union and in the CSSR, where, having been brought up in a very different environment, I expected that the situation would be distinctly different in many respects, particularly with respect to planning problems, overall objectives, and so on. What impressed me was that I was told about much the same kinds of problems that I would hear in the States, for example, the problems of unexpected high priority orders coming through that require frequent schedule adjustments, and things of that kind. It was a very interesting parallel.

Williams

In that case they are exactly the same, right?

Marguiles

May I just follow up on this?

You said, with respect to Williams' project, you would think that a greater involvement of the people concerned with the planning would be necessary. Can you give an example where such a procedure has been adopted? Can you explain where this would differ from Williams' approach?

Knotek

As was mentioned, the approach was just about the same.

Surguchev

I would like to comment on your remark about the difficulty of implementation. I think there are special features for each field of application, but our task was to try to find the common features. The general concept of integrated systems control, which was described in our state-of-the-art review might be difficult to implement in a real plant. It is an "ideal system" for an "ideal plant" that may not exist now. But general concepts and future trend considerations are very important.

Whitley

I would like to comment on this general discussion. Certainly, one of the things we have found, as did my friend from the CSSR, is that it is very important to involve the people that are operating the process or operating the schedule in the implementation of the computer system. Where we are dealing, as we are in some cases in the steel industry, with another company that is supplying the equipment, we insist that our people participate in the design and in the implementation, even though we are buying the system from another company, in order to assure the effective utilization of the product.

I think in the context of Williams' program and the question about what other advantages do we see from the particular approach that was laid out, one of the hopes I have from this program is to provide the alternative approach of breaking down the computer system into smaller parts that might facilitate the easier implementation of any given part by the local production people and still retain an overall concept that will be efficient throughout the plant. So, I think that is one of the advantages we hope to be able to get, to make it easier to get that local involvement and to allow them to proceed in a stepwise fashion as opposed to trying to implement the entire system of the entire plant at one time, which is difficult unless you are starting with a completely new plant.

de Gregorio

My comment is on Surguchev's paper. The model you use is a dynamic model, but deterministic. It could be very interesting to see from this model what would be the comparative effects on plant productivity under stochastic conditions, using manual control, static control, and dynamic control. In this way, we can come to appreciate the advantages obtained by using the proposed control.

Surguchev

Yes, you are right; the model is presented in deterministic form. It would be very interesting to test the model with stochastic data. We have had no opportunity to implement this model directly in a plant and compare the before and after situations. I am not sure that would be better. In further development of the model, it will be necessary to take the stochastic nature of the process into consideration.

de Gregorio

But it would be quite easy to test the model on stochastic data implemented through Monte-Carlo methods.

Surguchev

Yes, I agree. We are thinking about it just now, before developing the model any further.

Kovacs

I would like to comment on Whitely's views. If there is a factory, the full capacity of which is used, then some conflict of interests may occur inside the factory. For example, if there is not enough steel to fulfill demand, there will be a conflict of interests between the hot rolling mill and the cold rolling mill. Thus, even if there are smaller computers or other possibilities of working out the methods, I think this is much better than to have a large system. That is my first point. My other point is that, no matter how good a system is, somebody can find out why it is not good, if he wants to.

Kelley

Very true. I feel, though, that I sense a confused concept developing here. To my mind, because Williams described a system that involved the use of a lot of small computers; the control is local. I expect, however, particularly in the planning, the ordering of raw materials, and the allocation of steel that this is not so. Would you like to comment on that Mr. Williams?

Williams

You are perfectly right, Mr. Kelley. What we are assuming here, of course, is that there is a centralized planning and scheduling area and that we have at the first two hierarchical levels and a level of control. Obviously, you can implement these particular items in any order that you wish in terms of developing a total integrated system. The scheduling is done centrally, but it is done largely or completely during the implementation phase. It is done essentially as an independent system, and it would be able, of course, to operate in conjunction with the present system. At a later stage of implementation, a centralized planning and scheduling system could be added on top of the present control system . In this way, you could achieve the whole integrated system gradually.

Cheliustkin

Recently, I was talking with the people from the Hoogovens steelworks in Holland dealing with process control. They have some 50 or more minicomputers for process control, and they were satisfied with this control until they started to think about the future development of the works' automation. They have found that the capability of these minicomputers is not enough, and they intend to replace these with larger computers. So when you are defining the hardware to be used for a system, you have to consider how the information used at the process control level can be used also at the next level of automation. For instance, using a PDP 11 computer instead of a PDP 8, we can do not only process control but also part of the production control task.

Kelley

I do not know if anybody has any knowledge of what the Belgian steel company ARBED is planning, but I have just a sketchy report that they are moving in a direction of small computers very much along the lines that T. Williams has described for the works level. There will be a larger number of small computers in place of one enormous beast, even for the data processing and batch data processing work. I wish I knew more about this. Does anybody have any input on that?

Phaff

I say to Cheliustkin's remarks about Hoogovens that one of the most important factors in using larger computers--and programming people who use the PDP 11, agree with this--is the hope that we can use higher level programming languages so that we will need fewer programming people.

Surguchev

I would like to remark on the historical aspects of developing integrated systems control. Most steel firms started with the process control computer. In this event, they implemented small or minicomputers, and, later, when other problems such as planning or scheduling were considered, other hardware had to be introduced. Later, the firms went through some difficulties with linkages between different types of computers and so on. The example of the Hoogovens plant given by Cheliustkin confirms the situation.

Kopetz

I want to ask T. Williams what is his concept of integrating in a small computer the communication function and the process control function of the common data bank? Now, we feel that quite distinct and different functions should be put into separate machines. We would like to see, in our concept of the system, that the daily communications aspects, for example, when and from where you get the data, and where the data are to be sent, should be in a completely separate subsystem from the actual process control. Specifically, when you have data and your main structure has a very large data base, you come into problems of memory loss and so on. Could you comment on this?

Williams

As I understand what you are saying, the problem is that the data rate on some loops may make it critically important so that actually there would be two machines involved.

Kopetz

Specifically, consider also your reliability concerns for more parallel scheduling and for switching one way and another as conditions require.

Williams

Yes, I understand. As I understand the PLC and also the CAMAC, there is an address that precedes any transmission, and the real load on the system, in terms of taking data from the bus and getting the data back on the bus, is, of course, a question of identifying the address. We have felt that, as far as we have gone in our study--and in fact we probably have not gone as far as you have--that even though we have a very high data rate, we really only have to spend the time required to identify the addresses in each transmission and not really worry about the whole message. In this case, we feel that the computer, particularly for present day speeds, should be enough.

Kopetz

But you lock out the memory during the time of communication because the whole process must pick it from the memory.

Williams

In the addressing phase, only. In other words, if the message is not for me then I do not have to lock out the memory and I can ignore the message. If we have to worry about the address time, unless the address is for me, then obviously this time factor is important. But there is a lot of information going around the loop, and only a small part goes to any one user. Therefore, I think that there are points in our concept, perhaps, that are other than what you are thinking of.

The Role of Simulation in the Implementation of an Integrated Systems Approach

B. Mazel

Computer simulation has become increasingly popular among economists and management scientists as a tool for analyzing the behavior of complex economic systems in the last 15 years. The range of applications of computer simulation now extend from specific activities--on the level of a single plant, for example--to simulations of entire corporations and even of the economy of a whole country.

The term "simulate" is one that has come into vogue recently in a number of scientific disciplines to describe the ancient art of "model building". A common interpretation is that a simulation is an operating model of a real system. Some people in research consider almost any kind of model building. Others consider only models with special characteristics.

The modern use of the word traces its origin to the work of von Neuman and Ulam in the late 1940's, when they coined the term "Monte Carlo analysis" to apply to a mathematical technique they used to solve certain nuclear-shielding problems that were either too expensive for experimental solution or too complicated for analytical treatment.

So let us, for our purposes, accept the following definition of computer simulation: A numerical technique for conducting experiments on a digital computer, that involves certain types of mathematical and logical models that describe the behavior of an economic or technological system over extended periods of time. On the other hand, Monte Carlo analysis is a simulation technique for problems having a stochastic or probabilistic basis. Two different types of problems have given rise to the use of this technique.

First, there are those problems that involve some kind of stochastic process. Consumer demand, production lead time, and total investment for the economy are examples of economic variables that may be considered to be stochastic in nature. Monte Carlo methods have been developed for simulating most of the well-known probability distributions as well as many empirical distributions.

Second, certain completely deterministic mathematical problems cannot be solved easily by strictly deterministic methods. However, it may be possible to obtain approximate solutions to these problems by simulating a stochastic process whose moments, density function, or cumulative distribution function satisfy the functional relationship or the solution requirements of the deterministic problem. Solutions to high-order (greater than second order) difference equations and multiple integral problems can often be obtained more rapidly than otherwise by this method of numerical analysis.

For data-analysis, spectral analysis and multivariant analysis of variation and covariation are used, for simulation studies including time series. Also classical statistical analyses utilizing the comparison of mean square deviations of different experiments or case-studies are very common procedures for simulation.

THE PROCESS OF SIMULATION

The major appeal of simulation lies in its ability to aid to practical decision making, develop alternatives, variant plans, or courses of action to be considered by decision makers rapidly and at relatively low cost. Experiments using computer simulation techniques usually involve a procedure consisting of some basic steps (see Figure 1).

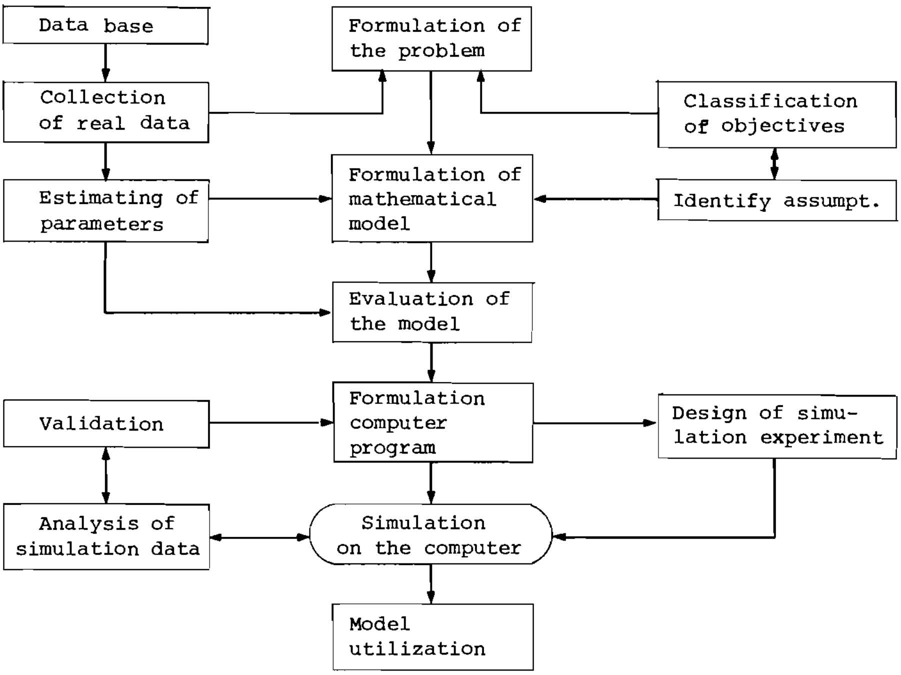


Figure 1.

As you see, there is a very similar procedure flow as for example, mathematical modeling, some operation research methods, econometrics, etc. One of the important parts of defining the purpose of a study is the specification of criteria by which the results of the investigation will be measured, validated, and analyzed, and assumptions will be identified, all with regards to objectives, etc.

For a job shop, performance can be measured in many ways: the amount of delay on deliveries; the amount of idle time; the amount of in-process inventory; the amount of scrap; the number of accidents; the quality of the items produced; labor turnover; profits made; etc. For a metallurgical plant some other objectives may be significant: optimal planning and scheduling of production; optimal performance of the equipment such as blast furnaces, hot or cold strip mills; optimal slab cutting strategy to minimize scrap; etc.

APPLICATION AREAS

We can find many interesting areas in industry where simulation techniques may be successfully implemented:

1) Material and production flow:

    - locating and removing bottlenecks in production process and production cycles (analyzing different interferences in queues);

    - balancing the work of production capacities;

    - checking the alternatives of investment proposals;

    - checking different rules for operational control of material flow (to get a suitable or optimal distribution of products, or maximum throughput, maximum profit, etc);

    - change of tasks and requirements.

2) Problems of stock-control:

    - setting an optimal level of stocks, reserves;

    - checking the strategies of stock control (to find rules that minimize the costs including costs of storage, losses, expenses for order dressing, etc.);

    - problems of overall stock policy.

3) In-plant transport:

    - checking the advantage of individual types of transport;

- checking the control rules (in connection with control rules of other departments involving production and stock levels);
- measuring the optimum, precision of fulfilling the tasks (timing) or economy of transport (costs).

These are all very common problems in the steel industry, and they occur not as individual problems but in various complex combinations. Particular attention has been paid to congestion problems occuring in the productions cycle, mostly in the steel making and in the rolling mill operations. For example, we mention the following:

a) In a multiple furnace plant, the crane capacity for handling the ladles often causes delays in tapping the furnaces.

b) Cranes in a melting shop have, in addition to the teeming task, a cycle of ancillary activity which often cause delays in teeming a cast.

c) In most steelworks, the stripping facilities are limited and delays prior to stripping are common. The lengthening of the track time by this and that delay in transport means that the necessary soaking time is increased. Attempts to cut soaking time lead to a deterioration in product quality.

d) The mills are subject to interruptions (for example, for roll changes or other maintenance); this delays the removal of ingots from the soaking pits which, in turn, becomes a source of congestion.

e) The finishing mill is frequently of lower capacity than the primary mill; as a result, the primary mill must operate on an irregular cycle to provide the required flow to the secondary mill.

f) Where secondary reheating furnaces are used, their limited capacity is a further cause of congestion.

In cooperation with the Institute INORGA, we have examined the problem, using simulation techniques, of how the operations of the casting bay and the stripping bay are affected if the annual production rate is to be increased by approximately 200,000 tons. This problem arises from a relatively complicated server-queuing system where serving channels are formed by individual components, the stripping bay, casting bay, rolling mill, etc. We based the study on a multiple-server queuing model, and used GPSS/360 as the simulation language, which appeared to be very flexible for this purpose.

The simulation method described has shown many advantages in comparison with other methods for determining how to increase production effectively without additional investments. In the present study, the desired objectives were realized in a relatively short time.

The making of steel products can be partitioned into departments that are easily identified by the functions which they perform. This is shown in Figure 2 as part of an integrated systems approach to using simulation techniques for planning and decision making.

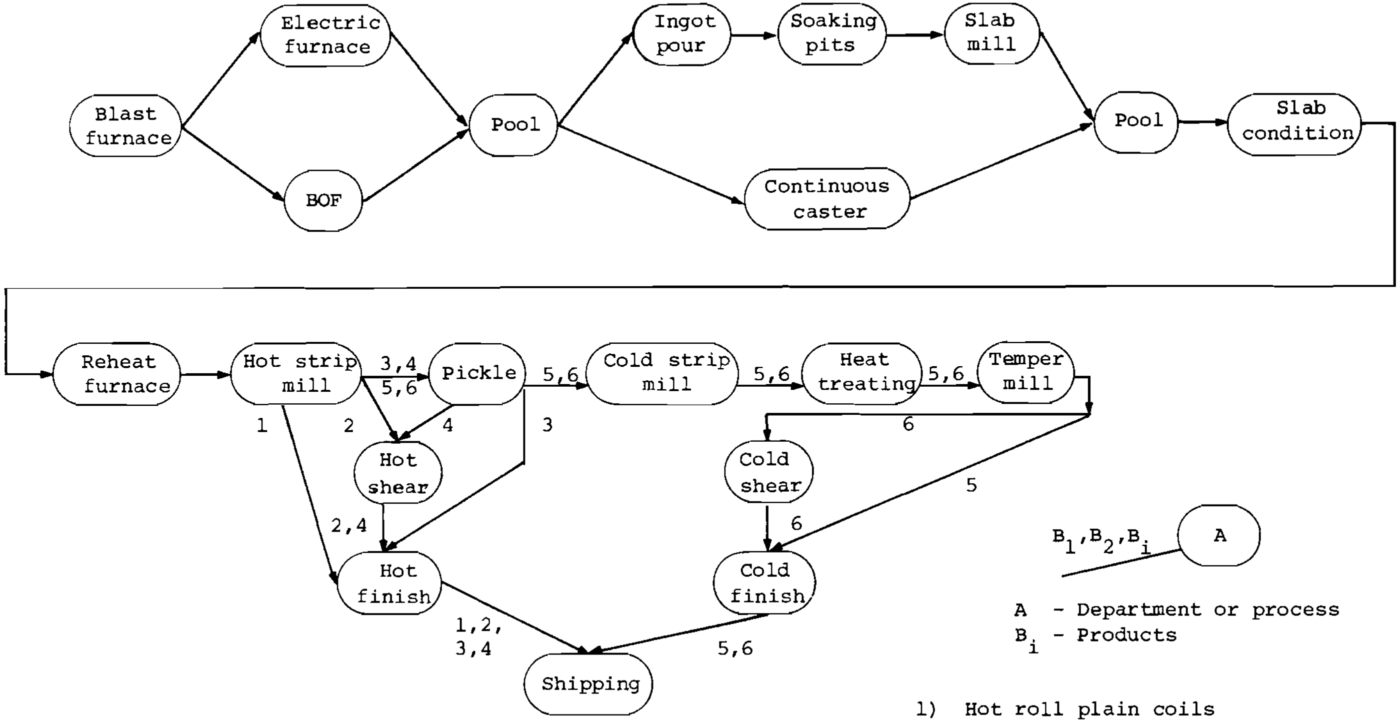
A wide variety of models can be constructed, depending on objectives. For some objectives, a simple, aggregated model is appropriate, while for others a highly detailed model capable of simulating the processing of individual orders is required.

A very sophisticated model was developed by the School of Industrial Engineering, Purdue University, for requirements planning in the steel industry, the so-called SNAP model. The objective of the model is to construct an aggregated network model of the steel plant for purposes of management analysis and planning. This model can relate the effects of stochastic variation of order quantities and of departmental yields, considering the effects of capacity constraints.

By combining an aggregate production planning model emphasizing product mix in the steel making process with an inventory planning and scheduling model, one can achieve near optimal results with respect to criteria such as product flow and/or profit. Before a scheduling model can be used, the desired tonnage for each of the products in each department is required. Determination of the desired tonnage for each node (department or process); the breakdown to individual products and the evaluation of their profitability, are the main functions of the program.

The philosophy of modeling a system in a network format and transcribing this information as data into a FORTRAN-based simulation language is identical to that of GERT, the Graphical Evaluation and Review Technique. For describing this network to the computer, a computer simulation language, GASP II/GASP IV, has been used.

The prime advantage of a network simulation is twofold. First, it enables management to evaluate the risk of various policies and decision rules in considerating the stochastic behavior of the aggregated system. Secondly, a network computer simulation abstraction of real-world processes makes use of man's ability to model these systems within a logical graphical framework.



A - Department or process
B_i - Products

1) Hot roll plain coils
2) Hot roll plain sheets
3) Hot roll pickled coils
4) Hot roll pickled sheets
5) Cold roll coils
6) Cold roll sheets

Figure 2. Generalized model of the steel making process.

The approach mentioned here for illustrating a practical use of simulation techniques can help by solving complicated situations in the planning system of an enterprise. Though there is no doubt that this part of production planning is very significant for assuring that required production levels are satisfied, nevertheless, it must be pointed out, that it covers only a part of a whole management and control system of the enterprise.

The application of simulation for the modeling of integrated industrial systems is still very complicated, and it has not been verified in practice for entire large-scale systems. This application is the main feature of the modeling approach shown in Figure 3.

In order to provide the means for experimental study of an integrated industrial system, a quantitative formulation of the various behavioral characteristics, component interdependencies, system flows, and stochastic functions is required. The formulation is used to develop a simulation program which can trace the activities of the system as they change in time. In this way, a large number of variables can be examined simultaneously, without explicit knowledge of their interdependencies.

The information generated by a simulation computer program could be used to effect decisions. Inputs to the decision network include the system constraints or policies, system functions, and environmental factors. These too can be represented by information flows via a communication network.

The study of the behavior of a total system requires an explicit description of the time dependencies among the components. The primary concern in the model discussed here is the conversion of resources into products and services. By determining appropriate strategies in relation to risks, it is possible to control rates of change of production, work force stabilization, growth rate, cost pricing, response to demand, and the relation of income to investment.

Since computer simulation may be used to trace the changes in the system variables over time, decision rules can be made functions of the actual values of the variables rather than their expected values. In this respect, simulation may differ from dynamic programming or gaming strategies which depend on statistical estimates as the basis for optimization.

CONCLUSIONS

It is apparent from many successful applications that simulation will continue to grow in importance and become a truly operational tool for management decisions. There is a vast number of problems that can be tackled, ranging from the study of specific economic problems to total company system problems. Because of its many advantages and because of the need for

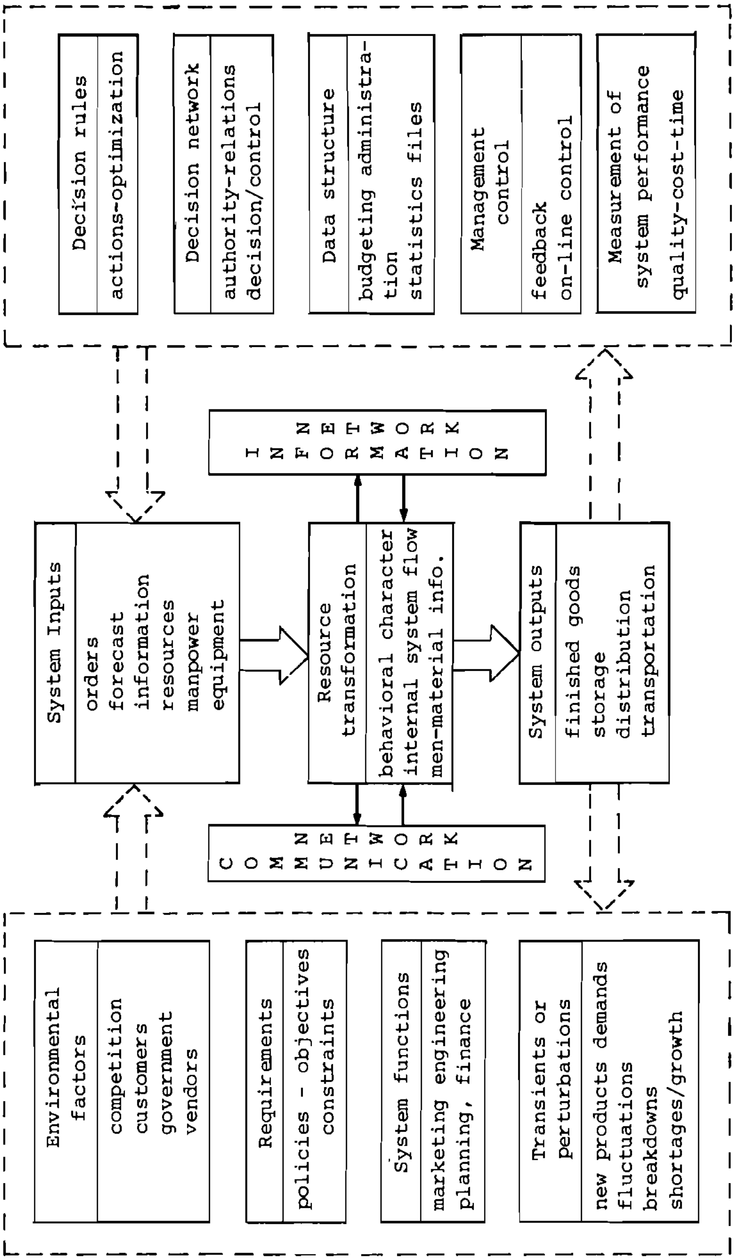


Figure 3. Activities and functions of an IIS.

improved techniques in management and control, simulation appears as one of the most useful tools that has come on the horizon. There is still much required to improve modeling, reduce programming costs, improve outputs, etc.

We can make, now, some recommendations for further use of simulation techniques for decision making:

1) Decision making can be coordinated with improved integration of events relating to disturbance effects through use of simulation techniques as a basic analytical tool.

2) Optimizing the capacity scheduling of individual sections of the system will enable the incorporation of the long-term planning for production and material flow in a single model (decisions on new investments, new equipment, etc.).

3) By combining an aggregate production planning model emphasizing product mix with an inventory planning model, a near optimal result with respect to criteria such as product flow and/or profit can be achieved.

4) The planning procedures can be accelerated using pre-prepared, standard simulation modules. An attempt to catalogue such programs and simulation modules should be very interesting and of importance for research and application.

Simulation of Material Flow in LD Steel Making Plants

M. Watzenböck

INTRODUCTION

Problem Definition

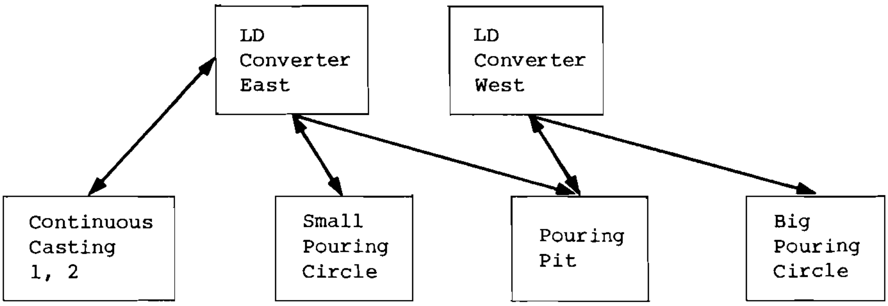
A model of the LD 2 plant was intended as a pilot study for an integrated material flow simulation project starting from the blast furnace and ending at the rolling mill including the facilities LD 1, LD 2, LD 3, at Siemens-Martin, an electric steel plant, and cold and hot rolling mills. The LD 2 simulation model had to serve as a planning tool for the installation of a swift continuous casting plant in order to determine

- the bottlenecks in the new system,
- the changes in the production program,
- the optimal output in case of breakdown.

The model was programmed in GPSS. Authors of the model were Bayer and Löffler (both Vöest-Alpine, Linz) and Watzenböck (IBM-Roece).

The plant economics department set a tolerance limit of 5%. The model has been tested on historical data with a deviation of less than 1% owing to the fitting of GPSS for the formulation.

System Overview



Formulation of the Production Program

The amount of production was measured in terms of converter charges per production class. Charges of similar quality, size and production times were assembled into classes. The percentage of all production classes on all facilities was the required input. In GPSS terms, the production classes were formulated as discrete functions.

MODEL AND OUTPUT DISCUSSION

Model Configurations

Model 0	(historic status):	
	W-Converter serves:	casting mill 1,
	E-Converter:	pouring facilities.
Model A	W and E-Converter serve:	casting mill 2, pouring facilities.
Model B	only pouring facilities	
Model C	W and E-Converter serve:	casting mill 2, pouring facilities.
	W-Converter only:	casting mill 1
Model D	W-Converter serves:	casting mill 1 casting mill 2 (alone and alternatively with other converter) pouring facilities.
	E-Converter:	No casting mill 1 service

GPSS Model

Program Symbols

1) Transactions and parameters
2) Facilities
3) Storages
4) Queues
5) Savevalues
6) Tables

7) Variables
8) Switches
9) Functions
10) Matrix savevalues

Transactions and Parameters - Converter

Parameter	West-Converter		East Converter
	Continuous casting	Pouring facilities	pouring facilities
P 1	Length of sequence	Number of intermediate charges	-
P 2	Pouring location	1 = pouring pit 2 = small circle 3 = big circle 4 = casting mill 1 5 = casting mill 2	
P 3	Class of production program	1-2 pit 1-6 small circle 1-6 big circle 1-4 casting mill 1 & 2	
P4	-	Number of circle charges	-
P 5	-	Pouring position	
P 6	-	Percentage of hot ingots	
P 7	Waiting time of converter = pouring time - heating time	-	-
P 8	Identification of converter	0	1
P 9	Labelled time point for synchronization of converters		

Facilities

KLEIN (1 - 5)	pouring location small circle
GROSS (11 - 18)	pouring location big circle
CHAKR	charging crane
GSKRO	pouring machine East
GSKRW	pouring crane West
STRNG	casting mill 1
STRN2	casting mill 2
TIOST	East converter
TIWST	West converter

Storages

GRUBE	pouring pit
ZUG	train for hot ingots

Queues

CHAKR	charging crane
GSKRW	pouring crane West
GSKRO	pouring machine East
GRUBE	pouring pit
KLGKR	small circle
GRGKR	big circle
STRNG	casting mill 1
STRN2	casting mill 2
ABHST	unhang time casting m 1
ABHS2	unhang time casting m 2
ABS	waiting for charge 1
ABST	synchronization

Savevalues

ABHST	unhang time casting m 1
STADS	deviation
CHARZ	changing time
BLASZ	blowing time
STBLZ	deviation
STADG	unhang deviation circle
STADG	unhang deviation pit

STGZK	pouring time deviation circle
STGZG	pouring time deviation pit
STGZS	casting time deviation mill 1
UMLGW	probability of quality devaluation
TOGRU	percentage pit charges from East converter

NUM1	number of casting mill 1 sequences
NUM2	number of casting mill 2 sequences
NUM3	number of pit sequences
TIME	labelled time for synchronization
GRGKR	pouring location on big circle

Tables

one table for all facilities.

Variables

WART1	converter waiting time, if casting mill 1 acts
WARTZ	if casting mill 2 acts
ABST	synchronization
KLGKR	pouring position small circle

Switches

TOGRU	(	Set = C.E. produces pit charges
	(	Reset = C.E. produces casting charges
ZUG	(	Set = GO
	(	Reset = WAIT
CHAR1	(	Set = Charge 1 of casting mill 2 sequence
	(	Reset = Charge $\neq$ 1
CHAR2	(	Set = Charge $\leq$ 2 of casting mill 2 sequence
	(	Reset = Charge > 2
LETZ	(	Set = normal charge of casting mill 2
	(	Reset = last charge of casting mill 2
SCHA	(	Set = synchronization considered
		Reset = not considered
SCHS1	(	Set = West converter produces for casting mill 1
		Reset = for casting mill 2
SCHTO	(	Set = East Converter produces for pouring pits
	(	Reset = East Converter produces for casting mills

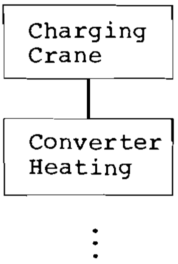
Functions

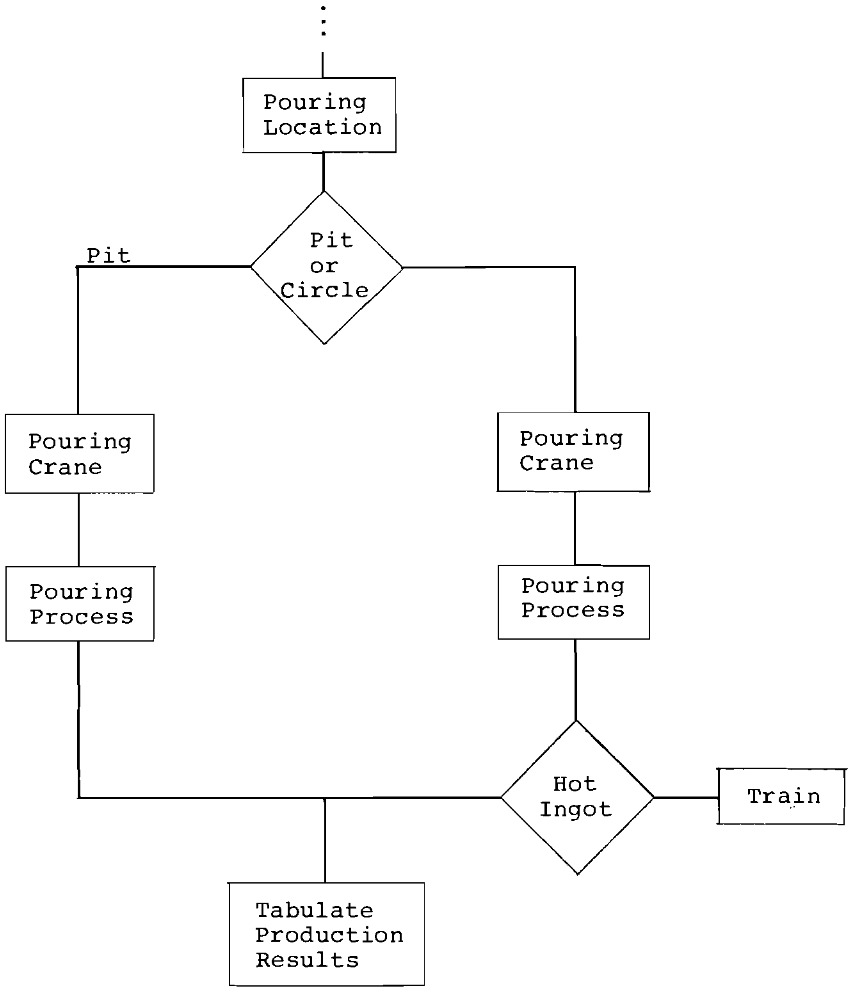
PPKGR	Production program pit
PPKKK	" small circle
PPKGK	" big circle
PPKST	" casting mill 1
PPKS2	" casting mill 2
SEQL1	sequence length (c.m.1) (time $>$ 38)
SEQL2	" (c.m.1) (time $\leq$ 38)
SEQL3	" (c.m.2) (time $\geq$ 38)
SEQL4	" (c.m.2) (time $<$ 38)
ZWIC1	number of pit charges after c.m.1
ZWIC2	" " after c.m.2
KRSCH	number of circle charges

Matrix Savevalues

GRUBE	production parameters pit row 1 unhang time 2 pouring time 3 standing time col. 1 - 2 pit classes 1 - 2
KREIS	row 1 unhang time 2 pouring time 3 standing time 4% hot ingots col. 1 - 6 circle classes 1 - 6
STRNG STRN2	production parameter casting mill 1 row 1 casting time col. 1 - 4 casting classes 1 - 4
PRODU	production results row 1 pit 2 small circle 3 big circle 4 casting mill 1 5 casting mill 2 col. 1 - 6 production class 7 totals

Formulation of Pouring Process



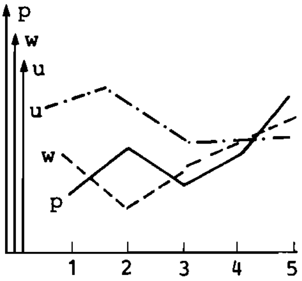


Formulation of Casting Process

```
TWSTR ASSIGN        3,FN$ PPKST          PROD.PROGRAMM-CLASS
      TEST G        MH$STRNG(1,P3),K380, +3
      ASSIGN        1,FN$SEQL1           SEQUENCELENGTH IF POURING TIME
                                          38 MIN
      TRANSFER      ,*+2
      ASSIGN        1,FN$SEQL2           SEQUENCELENGTH IF POURING TIME
                                          =38 MIN
```

```
        SAVEVALUE       NUM1+,K1
        SAVEVALUE       SUM1+,*1
        SAVEVALUE       SEQL1,*1
        ASSIGN          2,4                 POURING LOCATION=CASTING MILL
        ASSIGN          7,V$WART1           WAITING TIME CONV=POURING-HEATING
WART1   VARIABLE        MH$STRNG(1,P3)-X$CHARZ-X$BLASZ
        TRANSFER        ,CCC
LOOP2   TEST E          *1,K1,*+2           LAST CHARGE OF SEQUENCE
        SAVEVALUE       SEQL1,KO            SEQUENCE LENGTH=0 SET BACK
        QUEUE           STRNG
        ADVANCE         *7                  WAITING TIME OF CONVERTER
        DEPART          STRNG
  CCC   PREEMPT         CHAKR,PR,XXXXX,,RE  CHARGING CRANE
        SEIZE           TIWST
        ADVANCE         X$CHARZ             CHARGING TIME
        RETURN          CHAKR
        ADVANCE         X$BLASZ,X$STBLZ     BLOWING TIME
        RELEASE         TIWST
        TEST E          *1,K1,DDD1          LAST CHARGE OF SEQUENCE

        TRANSFER        ,X$UMLGW,DDD1,UMLE1 DEVALUATION OF QUALITY
UMLE1   MSAVEVALUE      PRODU+,P2,6,1,H
        MSAVEVALUE      PRODU+,P2,7,1,H
        QUEUE           STRNG
        ADVANCE         *7                  CONVERTER WAITING BECAUSE OF
                                            DEVALUATED INGOT
        DEPART          STRNG
        TRANSFER        ,TWBLO

 DDD1   SPLIT           1,DDE1
        TRANSFER        ,STRNG              TO CONTINUOUS CASTING
 DDE1   LOOP            1,LOOP2
        TRANSFER        ,TWBLO              TO POURING PIT

        STRANGGUS-GIESSVORGANG

 STRNGSTEST E           *1,X$SEQL1,EEE      FIRST CHARGE OF SEQUENCE

        QUEUE           ABHST               UNHANG TIME OF CASTING MILL
        ADVANCE         X$ABHST,X$STADS
        TRANSFER        ,*+2

  EEE   QUEUE           ABHST
        SEIZE           STRNG
        DEPART          ABHST
        ADVANCE         MH$STRNG(1,P3),X$STGZS POURING TIME
        RELEASE         STRNG
        TRANSFER        ,TAB                TABULATE PROD.RESULTS
```

Questions to be Answered by the Model

Question Number	Decision Variables			Graph of Results
	Model Configuration	Product Program	Others	
A 1	C, D	1 - 5		
A 2	A, C, D	1 - 5	Heating Time	
A 3	A, C, D	1 - 5	Converter Capacity	
A 4	A, C, D	FIX	Sequence Length	
A 5	A	1 - 2	Percentage Pit/ Cast.M	
B 1	0	2 - 3	-	
B 2	B	5		

Future Planning

A number of factors should be considered in future planning. Which of the selected production programs gives best results concerning production, waiting time, and utilization of facilities? If the speed of the casting mill can be increased, the heating time will be decreased, thus it is necessary to discuss the effects of decreasing heating time on casting mills. If converter capacity is increased in steps of five tons, how is output affected? Which sequence length gives optimal results? Which percentage relation of casting charges to pit charges gives good results?

Present Planning

It is important to take into account what is the present maximal output? What is the output in the case of a breakdown of both casting mills?

CONCLUSION

The examples covered may give some ideas on the formulation of flow of materials in basic oxygen plants, as they were used by Austrian steel plants. Our Czech colleagues formulated the flow of materials in classical steel making plants. The integration of both models should be possible and is considered a step forward in the simulation of the complete steel making process.

Discussion

Surguchev

Mr. Mazel, could you comment on modern tendencies in simulation languages?

Mazel

Since my presentation time was so short, I did not describe any experiences in using different kinds of simulation languages. In the literature and also in practice, the most popular simulation language for discrete systems appears to be GPSS, because it was promoted by IBM. Simscript and SIMULA are also very popular for discrete simulations. SIMULA was developed by a group at the Norwegian Academy of Science, and is known especially in European countries, though not so much outside Europe. There are good results from using other languages like CSL, and that was mainly in Britain. For simulative continuous systems there are CSSL, CSMP, and Dynamo. I would mention that the tendency now is to use simulation languages that combine both discrete and continuous sytems. Among the best results in this field are the GASP II and IV languages which were developed by Pritsker at Purdue University.

Cheliustkin

Mr Watzenböck, what result did you obtain when you considered the practical implementations of the decisions from the simulation models?

Watzenböck

Well, you know, the result of simulation is that what you give as input you normally get as output. It is only a question of good formulation for the simulation model. And to be precise, most of the answers we got were also answered by the practical people beforehand, and, of course, they had to be the same because I think simulation cannot replace practical experiments or practical experience. But it can support this practical experience and say "even my mathematical model says the same as you suppose". If the model and the practical experience differ, it is generally the simulation model that needs to be corrected and not the practical experience.

Lefkowitz

If you take that point of view then what purpose is served by the simulation procedure?

Watzenböck

Well, simulation gives you a good estimate of time. Where does time waste occur? On which facilities? As Mazel described it, it occurs on cranes, but if you ask the operating personnel they will deny that it is the crane. You can hardly change the social mode of these crane operators, but in constructing new LD steel plants you can ensure that enough cranes are provided, if you find that is a bottleneck. And you can clearly identify where the bottleneck exists by a time analysis. You can testify to what the practical steel makers suppose. You can testify by giving a time estimate and a time comparison. That is what I think simulation is good for. To give facts and to support ideas.

Phaff

I wonder how it is possible to make a model of the BOF plant without making a model of a very complex system.

Watzenböck

Yes, you know models have to act as black boxes where you consider something as an input and something as an output. We found that an upper limit for a GPSS model is about 300 statements. With 300 GPSS statements we could only formulate the situation in an LD plant and not include the blast furnaces. If we had included the blast furnaces, we would have had to choose a bigger unit for the transaction, let us say grouping of charges of similar quality or something like that. The bigger the model you make, the bigger the black box is. But for our purpose, let us say, for the time analysis in the LD plant it proved to be enough to have the model of that size. But to consider an integrated plant, I do not think my model would be very useful.

Wieser

I would like to comment again on your question. In the Linz plant there are five blast furnaces and three LD plants.

Watzenböck

Just one LD plant.

Wieser

Are we to go on the assumption that this one plant is available with a mixer?

Phaff

That is right because we are building the same kind of plant in Holland. We need a model corresponding to the Austrian system.

Watzenböck

Yes, I see. I would be very interested in what you choose as the unit of transaction. Have you already decided?

Phaff

No, it is not yet known.

Watzenböck

Because this is clearly the basic unit of the simulation model. It identifies the simulation model or, in my opinion, makes one simulation model comparable to another.

Kelley

I personally am still slightly confused as to whether the GPSS restricted your sphere of interest and that you really would have benefited from simulating a larger area. The experience from my own country--the last big steelworks we built was in Newport and there we did not use IBM software--is that we simulated many aspects of that plant before there was anything in existence; for example, we calculated the size of the mixers purely by simulation of the blast furnaces and the steel plant, and in that case there was no opportunity for anybody to say your answer is good because it is what I expected. This was part of the design procedure. I think it was proved in practice to be a satisfactory procedure.

Cheliustkin

And have you used the Monte Carlo method?

Kelley

Yes, we obtained the form of the distribution from data from other plants in existence, and we took the limiting conditions from the estimated production of the new furnaces. It proved to be a very realistic way of doing it.

Watzenböck

Which simulation language did you choose?

Kelley

We did it in machine language. This was in 1958-1959.

Watzenböck

Well, this trend is also followed by IBM with the formulation of Simscript, which is similar, because the logic of a model is not so easily formulated in GPSS. But GPSS always returns in popularity, while most other programming languages disappear.

Integrated Production Planning and Control Systems in the Iron and Steel Industry

H. Pötzl

There is an increasing demand for goods of all kinds and for the finances and other requirements for providing these goods. Since we want to produce these goods as economically as possibly, we need to find the necessary facts of production by which the decisions leading to minimum costs, may be determined.

The growing complexities of production systems do not allow management making decisions based only on intuition, improvization, or experience. However, we can handle the complexity by employing mathematical methods for planning. Usually, the elements of the complex system are interconnected in such a way that it is impossible to describe them exactly; however, through the simplification of reality in a mathematical model, we are able to find the effects on the production of each relevant factor. Thus, the solution of the model allows us to find the solution to the real problem.

Until recently, the large number of system elements prevented the complete representation of all their interconnections. This has also led to major difficulties in the solution of these problems because of their size and complexity. Another source of difficulty is introduced by stochastic system elements, for example the effects of interruptions of production or variations in worker efficiency. These stochastic influences can be minimized by automated processes, planned maintenance procedures, and integrated planning and control systems.

Lately much has been done in the iron and steel industry to automate the production processes, especially in the automatization of the rolling mills. Now, controlling the rolling mill process does not present any difficulties. There are also reports of successful automation of the blast furnace and the steel making processes. However, there is much more development work to be done before we can have a full and practical automation of the plant.

In addition to describing the automation of individual process units, it is necessary to solve their interconnections.

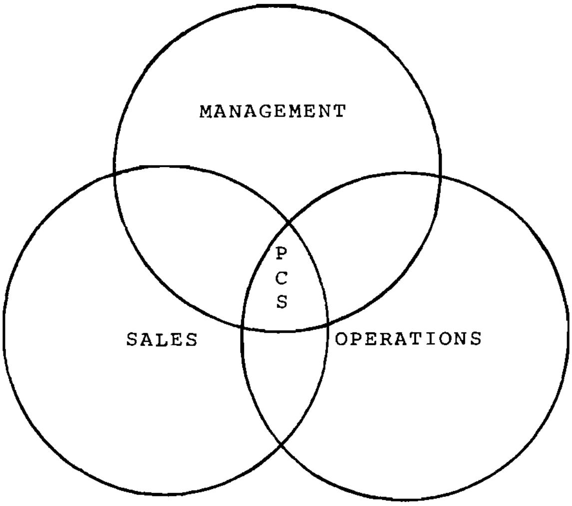
The descriptions of the individual elements of the system and their interconnections, including the nature of their time dependencies leads to mathematical descriptions which form the basis for the integrated planning and control system.

The function of an integrated planning and control system is to provide the means for an optimal production of goods; hence, it must include an information system that connects the individual departments of the enterprise.

In essence such an integrated planning and control system has two functions. First, the entering orders must be planned for in future production, and an order sequence plan must be made. Second, the data necessary for the preparation of the order must be fed in at the right time to the right place. An integrated planning and control system must be able to take over the complete organization of order processing and handling.

The major departments of an enterprise may be identified as (see Figure):

- management,
- sales, and
- operations.



Departments of an enterprise.

The integrated planning and control system interconnects these functions, and carries out all the data logging, data transmission, and data processing necessary for the optimization of production.

The sales department is the input unit of the integrated planning and control system. The completion time for each order is estimated on the basis of the order specifications and the planned operating levels of the production units. This information is then transmitted to sales.

If necessary, special delivery terms can be considered by setting priorities in the production planning stage.

In addition to the data processing, the integrated system must be able to determine an optimal distribution of the orders to be processed on the various facilities and also an optimal order sequence. These results must be translated into operating instructions which are transmitted to the works at the appropriate times for implementation, followed, finally, by feedbacks signalling order execution. These feedbacks present the possibility of a comparison between planned and realized values which may be used for correcting the previously determined schedules and plans.

The integrated planning and control system is based on three phases of operations:

- order preparation,
- order scheduling, and
- order execution.

The operations concentrate essentially on three functions. The first function includes the input and logging of raw data into the integrated planning and control system. The second function includes the logging of the technical requirements for order execution. The third function includes the rough term planning for the production plant.

In the framework of the order entry, the arriving customer orders are transferred to a data recording medium for data processing and storage. Encoding of customer demands is done at this time. This function of an integrated planning and control system largely has been solved, and it is applied in the iron and steel industry.

The second phase in the development of an integrated planning and control system includes the listing of the technical demands for the order execution. This is essentially the determination of the necessary input material in connection with stock problems, and the fixing of the possible processing route. The result of this work is the order schedule, which presents the basis for order planning. Lately, great efforts have been made in this field and practical solutions also have been found for the rolling mill department. Because of the different structures of various plants, general solutions to the order planning problem have not been found. This difficulty may be overcome by the development of special models that are directed to the specific problem to be solved. These models may relate to raw material allocation, order transit scheduling, and facility scheduling.

Last but not least, solutions for order planning in a determined production period have been developed. For the solution of these problems generally available models that are directed to special production structures have been developed. These models are based on the specified terms of delivery and they try to determine the start of the order execution on each facility with regard to fixed conditions and priorities. Programs of this kind are already used in the iron and steel industry, and they have brought about a decrease in the required running time of orders.

The problems of production control were not solved until recently. These problems include the determination of an order sequence directed to optimize production with special regard to minimizing stock, maximizing facilities utilization, and observing delivery terms. The solutions are directed to finding decision rules for determination of order sequence. These decision rules are shown to be effective with the help of dynamic simulation models of the plant processes.

Partially, process control problems have already been solved as, for example, in the changes in order coordination in heavy plate production when there are faults in the final product.

Another special problem in the iron and steel industry is multiple production. The solutions developed here are directed at only small, limited departments, and they cannot be expanded to a total system. The large amount of data and the complex structure of the iron and steel industry permitted only very simplified solutions until recently, but these solutions are not yet used in practice.

Efforts in the development of integrated planning and control systems in the future must be directed to the development of mathematical methods for solving combinatorial problems rapidly and efficiently.

Aside from creating new mathematical methods, computers also must be improved to achieve larger capacities and higher computing speeds. Only then will it be possible to process the large amount of data necessary for the representation of factorial reality and to find solutions to the real problems occurring in practice.

Discussion

Cheliustkin

How do you determine the time horizons for scheduling of the different stages of production? As the time you are considering lengthens, the more complicated the problem becomes and the more limitations are imposed by computer capacity. So is there a trade-off between the time horizon and the feasibility of the problem solution?

Pötzl

I think I understand your questions, but I cannot answer them.

The Current Status and Future Aspects of Management Information Systems

Y. Maekawa

DISCUSSION OF MIS IN JAPAN

About eight years ago, in 1967, an investigation team was formed by top Japanese business leaders to study the applications of Management Information Systems (MIS) in the US. The team published a report that was very controversial and that resulted in a reaction, the so-called "MIS boom". Many articles and books concerning MIS were translated and published, and there has been much active study and discussion on the subject.

Initially, the MIS that was researched and discussed was so idealistic and impractical that is was hard to realize. Management information specialists criticized the system and called it an impractical and unrealistic system. However, it is true that the "MIS boom" helped to advance research concerning MIS. The research concerned itself with which direction information utilization should progress, how to improve the management information system, and how to develop and to improve the computer data processing systems in Japan.

FORMATION OF A PRACTICAL MANAGEMENT INFORMATION SYSTEM AND CURRENT STATUS

As time passed, the study and development of a practical MIS was started. Leading firms steadily developed and formed a practical MIS, exploring integrated systems concurrently. Many articles and data are available that describe the present day situation of MIS in Japan. Here we are going to cite the data published annually by the Federation of Iron and Steel, Japan.

THOUGHTS ON MIS

No one would dispute the abstract definition of MIS as an information system to contribute management activity in an organization. It is hard to derive a concrete and commonly accepted definition of MIS. This is so because many people with their own ideas, backgrounds, and experiences define it in their own ways.

My own definition derived from my experiences developing a MIS is as follows:

1) MIS varies according to the situation in each company. Each company has its own purpose, plan, schedule, and intended coverage to develop information systems. MIS must meet each company's requirements as an information system developed for its particular organizational needs.

2) MIS expands as companies change their expectations concerning the information system particularly as the systems develop from only partial systems to totally integrated systems.

3) MIS needs long-range development plans concerning the information system. In forming an information system, we generally first start with developing the operational systems and next the strategic systems. The hierachical structure, including both strategic and operational systems, is needed for the efficient performance of MIS. Therefore, the long-range development plan should be definitely scheduled at the beginning.

4) MIS can be realized with computer information technology applied to data gathering, data banking, data utilizing, and data supplying.

PROBLEMS ASSOCIATED WITH DEVELOPING MIS

Many problems occur during the development of MIS; some of these are as follows:

1) A strong organization to control and develop the entire company's information systems is needed to develop, maintain, and control MIS.

2) Developing an information system needs a great deal of money and time and the resulting system must satisfy the company's needs. For this purpose, excellent system engineers must be available in both quantity and quality and the educating of system engineers is very important.

3) Developing information systems needs the cooperation of related departments. Their understanding, eagerness, and expectation to develop information systems greatly affects the quality of the resulting systems.

4) High utilization of computers increases the costs of computers and operations.

5) We can expect such merits as speed, accuracy, efficiency, etc., by utilizing computers, though we have some mobility problems to cope with from the changes. We introduce on-line, conversation-type, application program packages to avoid this problem.

6) It is hard to develop an information system to meet perfectly the expectations of top and middle management.

7) It is likely that MIS will take the form of utilizing information received regardless of its source. However, if erroneous data are fed in, then they may lead to a wrong decision that will affect the whole system. Therefore, it becomes imperative to guarantee the validity and security of data and to define system responsibilities.

REQUIREMENTS FOR DEVELOPING FUTURE MIS

If we take the above mentioned experiences and problems into consideration, the following steps and requirements seem to be necessary to develop and improve future MIS:

1) To train and to educate system engineers and electronic data processing specialists is necessary; furthermore, in Japan it is quite necessary to educate and train the department managers who control, operate, and utilize the information systems.

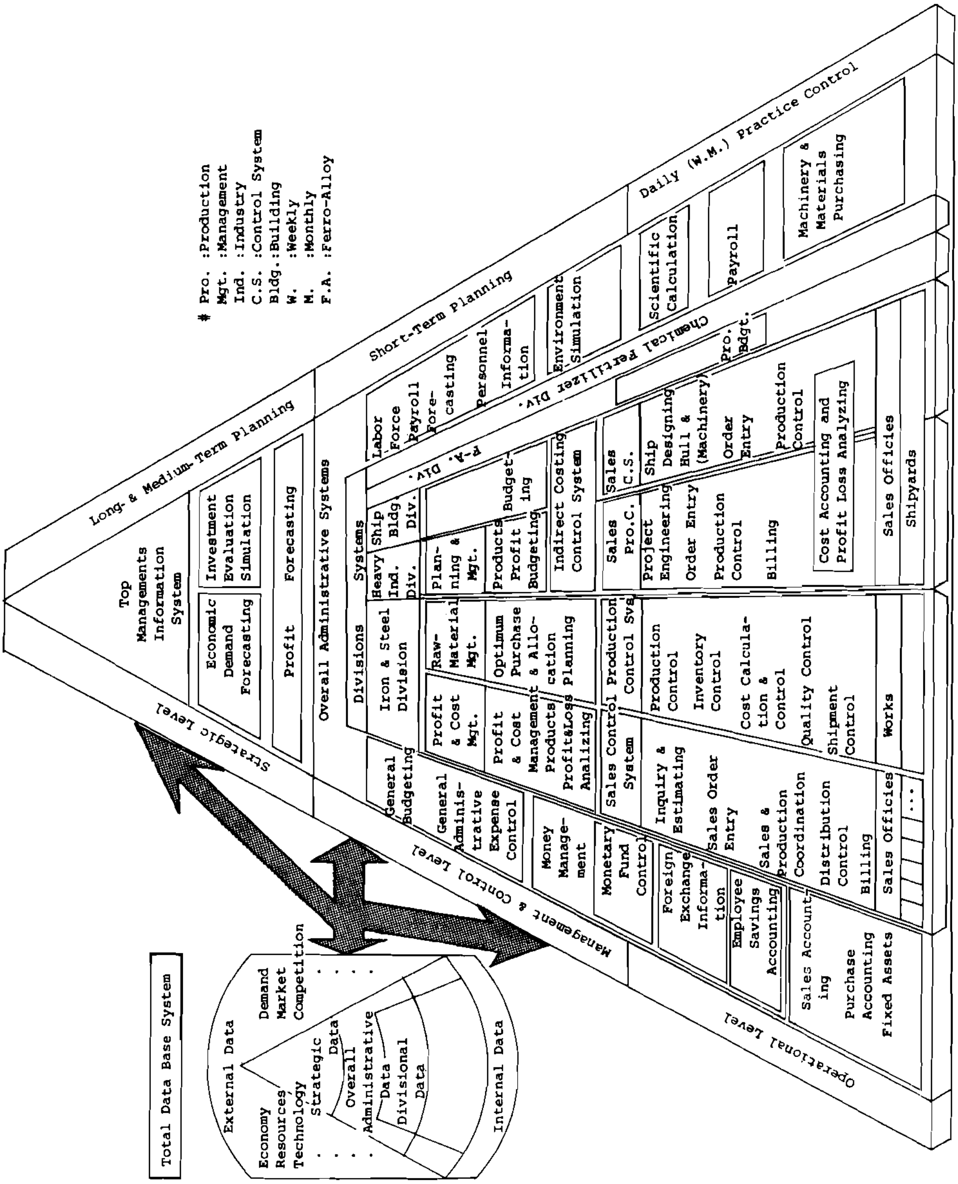
2) To study and develop a corporate planning system that occupies the upper position of MIS.

3) To study and develop a data base system for efficient gathering, utilization, and accumulation of information.

4) To introduce and incorporate the functions of the computer and its terminals and the methods of management science into the whole information system.

5) To make it possible for fast access to the programs for data processing and utilization to meet the needs of management at various levels, to develop information retrieval and supply programs.

See the figure of the general structure of a Management Information System and Data Base System.



General structure of Management Information Systems and Data Base Systems.

Discussion

Kopetz

What percentage of the turnover of the Japanese steel industry is spent on the management information systems?

Maekawa

In the Japanese steel industry approximately 0.3% to 0.5%.

Whitely

Do the data you provide relate only to business computers?

Maekawa

Yes, that's right.

Whitely

Not just the blast furnace plants?

Maekawa

No.

de Gregorio

What is the benefit that you expect from this development?

Maekawa

To help the manager in decision making, and also problem solution and cost reduction.

Phaff

We have been talking about modern competitive problems. In your opinion, have they been solved sufficiently in this respect?

Maekawa

It depends on the software programs. We must develop new ideas for quickly prepared programs for information retrieval.

Phaff

Is the program that you have sufficient in your opinion?

Maekawa

Of course we do not think so. It is very difficult to make.

Williams

It is very difficult.

Kelley

On this question of software: Have you in fact programmed your own software or have you used some existing packages that handle this sort of problem?

Maekawa

We used some already existing packages, for instance an IBM package for the optimization of raw material resources and things like that. But we developed most of them ourselves.

Kelley

Is your program commercially available? Or do you keep it to yourself?

Maekawa

Generally we keep it to ourselves, but some of our package programs were shared with other companies in Japan.

Cheliustkin

Some companies use rented computers and others are buying their own computers. What is the regular practice?

Maekawa

Most companies use the rental system, but banks and insurance companies are buying their own computers.

Cheliustkin

I mean the steel companies.

Maekawa

Most of the steel companies use the rental system.

Cheliustkin

And what is the reason? Is it because of financial problems?

Maekawa

Yes, and also because of rapid changes; about three or four years later we must change the systems to new ones.

Kopetz

How much effort do you spend on software maintenance compared to the original development in each year?

Maekawa

In personnel or in money?

Kopetz

Well, what do you take as basis?

Maekawa

For instance, my section has 60 programmers, 65% is for program maintenance.

Kelley

You mentioned that it is important to have a fast response time or retrieval time. Is it possible for you to give us some figures on how much time it takes to retrieve a particular element of data?

Maekawa

In the head office, the main computers are installed on the fourth floor, and, for example, the financial department has their own machine on the eleventh floor. The computer in the financial department is closely connected with the main computers, and it is possible to retrieve a particular element of data immediately. However, in practice some factories use data sent from the head office in Tokyo, and that distance is about 700 km. The head office sends order information to each factory every day, and their responses come back one or two hours later.

Whitely

I would like to have a further explanation of your statement "d) High utilization of computers increases the costs of computers and operations.". Do you mean the use of many computers increases the cost of computers or is cost increased by the high utilization of the computer, that is, how effectively it is used?

Maekawa

Our long-range plan of developing our information system shows this structure. Some systems have already been developed, but we must always develop a new system. In this case, the necessary money and time for the computerization operation and operating costs will increase.

Whitely

Are you saying the more computers you use the higher the cost?

Maekawa

That is right, particularly in the information systems field.

Whitely

Let me ask you a different question relating to hardware utilization. Do you measure the utilization of a given computer, for example how much the memory or other components of the computer are being used? Are there certain standards that you apply to determine whether you are using a computer effectively?

Maekawa

Yes, when we start the design of new system, we first estimate roughly the merit and cost of computer utilization and also the expense of the computer itself. Then after this evaluation we start the programming.

Whitely

I will talk to you later.

Long

What types of management information systems are not yet developed?

Maekawa

Top management information systems. Some attempts are now going on, but it is a very difficult task.

Mazel

Do you have some mobile computer utilizations, for example, for the purpose of some simulations in process control?

Maekawa

Yes, quite right, we do that.

Integrated Industrial Systems and Environmental Management

Y. Sawaragi

As a result of the rapid industrial development of recent years, human beings are facing a huge problem, that of environmental pollution. It is urgently necessary that we tackle this problem from a scientific point of view. Furthermore, as environmental quality constraints will become more stringent in the near future, industry must take into account their impacts beforehand and from a very broad point of view.

Since the next speaker, K. Ito, will speak about environmental pollution problems in the steel industry in more detail, I would like to describe to you some aspects of such problems from a broader point of view. Let me first try to explain some fundamental concepts of environmental management from the viewpoint of systems science, and then I want to describe a special project of environmental pollution control that I organized in Japan.

First of all, let me try to classify the environmental pollution problem using the five dimensional Euclidean space as shown in Figure 1. In Figure 1, T denotes time scale, S is the

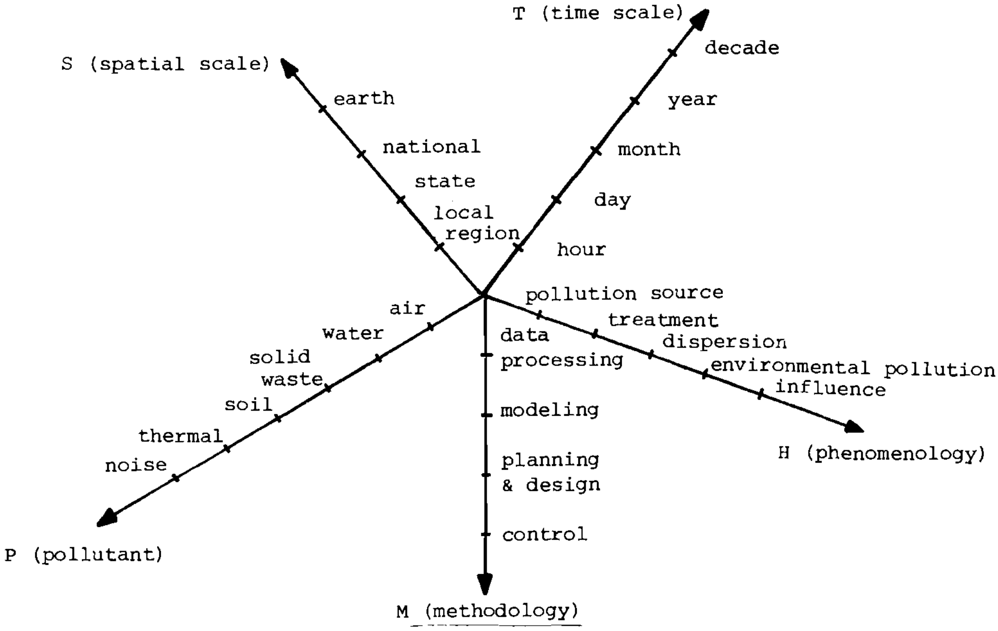


Figure 1.

spatial scale, P is pollutant, M is methodology, and H is the phenomenology axis. It is important to define, at an initial stage, the environmental pollution problem exactly and scientifically using this diagram. As an example, if we focus our attention on the P and M axis, a matrix diagram such as shown in Figure 2 will be obtained. Using this matrix, it is then very easy to classify some special topics of environmental pollution control problems systematically. In more detail, the intersection of air and data processing identifies a research theme of digital simulation of air pollution, and the intersection of air and modeling suggests research on diffusion models of air pollution. Another example is the combination of stochastic control with traffic, which leads to the problem of control of traffic congestion.

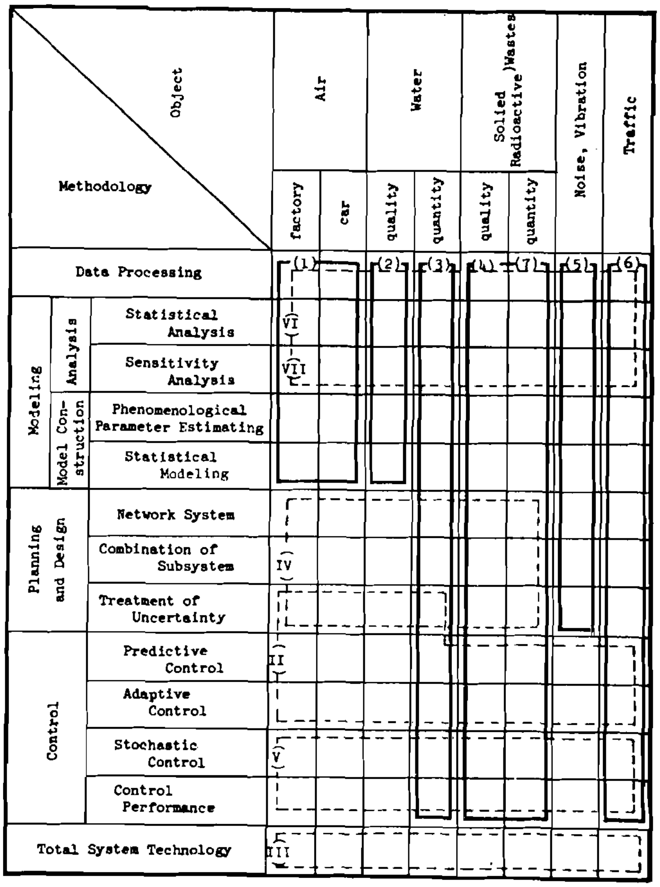


Figure 2.

Figure 3 outlines one fundamental aspect of environmental management. Here, we must evaluate the influence of the pollutants and establish proper emission standards or standards of environmental quality. Next, we must construct a monitoring system, so that if the measured pollution value exceeds the environmental standard, then this information may be fed back to affect the treatment process, or, as sometimes necessary, to modify the level of production.

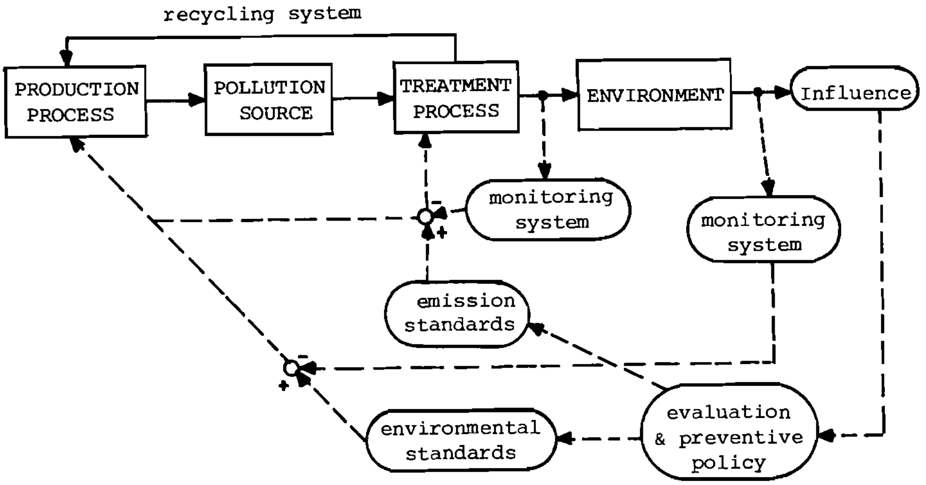


Figure 3.

We must also take into account the interrelationships of various types of pollution phenomena. For example, if we treat water pollution, it produces solid waste, and if we burn solid waste, it pollutes the air. Therefore, we have to research pollution sources, not as independent phenomena but as interrelated pollution phenomena from a total systems viewpoint.

Now, let me explain a special project of environmental pollution control in Japan. The project has been sponsored by the Ministry of Education for the three year period from April 1972 until the end of March 1975. There were nearly 200 engineers and scientists gathered from some 40 universities in Japan engaged in the project which was under my direction.

The project was classified according to the matrix shown in Figure 2, and 14 groups were organized by objects and by methods. For example, Category A) consists of groups of phenomenological researches, and Category B) consists of groups of methodological researches (see Tables 1 and 2). Note, in particular, that

Table 1.

A) Groups of Phenomenological Researches:

1) Analysis and modeling of diffusion process in air.
2) Prediction and control of water quality in water basin.
3) Water flow control and environment control in river basin.
4) Areal control of water and solid waste as materials flow.
5) Analysis of the propagation process of noise and vibration.
6) Traffic control for air pollution and noise.
7) Modeling and identification of the control system of atomic plant and its environment.

Table 2.

B) Groups of Methodological Researches:

1) Systematization of the researches on environmental pollution control.
2) Methodology of environmental control.
3) Total system approach to environmental planning.
4) Methods of estimating the state and treatment of indeterminate variables for the design of environmental system.
5) Computer system for environmental control.
6) Data transmission and processing of the environmental state.
7) Air observation by laser and the analysis of the environmental system.

group B-1 is set up for the purpose of organizing other groups. The results of this project have been summarized,[1] and include more than 150 research studies.

We are also planning to publish a book later this year concerning the project. A sample of some of our theoretical results is given in the paper "Multiplier Method and Impact Analysis of Environmental Policy on Process of Systems Design". The Ministry of Education in Japan has now decided to support a new project on environmental problems for an additional three years. You will find the detailed description of this project and related projects in the paper "Some Comments on the Long-Range Planning of an IIS Project". In this paper, you will see the current situation in Japan for various research projects related to environmental problems and for research activities in systems science.

Through this research, it was recognized that, since the environmental problem is related to many diverse disciplines such as engineering, economics, ecology, medicine, and so on, it is absolutely necessary to attack this problem from an interdisciplinary point of view. Finally, the problem is very integrated and complex and therefore, I feel that it should be studied by applying the most advanced methods of modern systems science.

---

[1] See Research Abstracts, (January 1975), "Environmental Pollution Control," April 1972-March 1975, Special Research Program supported by The Ministry of Education, Japan.

Impact of Environmental Constraints in the Steel Industry

K. Ito

Since the iron and steel industry is a very large, complex system, its pollution phenomena are many and varied; they cause air, water, soil, and thermal pollutions, solid wastes, noise, vibration, and offensive odors. Therefore it is not an easy task to discuss the pollution problem of the steel industry within the short time that I have. But I would like to explain briefly some aspects of pollution problems based on data from Japan.

First of all, let us recognize that the iron and steel industry consumes large amounts of raw materials, energy, and water, and that it exhausts air and water pollutants and solid wastes into the environment. As an example, Table 1 shows the amount of heavy oil consumed by Japanese industry in 1970, and it shows that the quality of heavy oil used by the iron and steel industry is at a relatively low level. Further, the consumption of coal by each industry in Japan in 1970 is shown in Table 2. It shows that 63% of the coal used was consumed by the iron and steel industry. Because of this large consumption of fuel and raw materials, the iron and steel industry generates huge amounts of sulfur oxides that are emitted into the air as shown in Table 3.

Concerning water resources, fresh water is recycled relatively well in the iron and steel industry as shown in Table 4. However, this table also shows that the amount of fresh water used by the iron and steel industry is still very high. In addition to fresh water, the amount of sea water required for cooling is two to three times that of the fresh water needs. As a result, it is necessary to treat large amounts of waste water; let us return to this problem later.

Next, let us briefly discuss the solid waste problem in the iron and steel industry. Table 5 shows the total amounts of solid wastes exhausted by each industry in Japan. Though the amounts of solid wastes generated in the iron and steel industry are very large, and they are relatively well reused by other industries, as for example, the use of blast furnace slag shown in Table 6.

As a basis to consider environmental management in the iron and steel industry, it is absolutely necessary to build a model that clarifies the input-output relationships of the whole plant. It must include the relationships between raw materials, energy, water, products, pollutants, waste materials, etc. A simplified

Table 1. Heavy oil consumption by industries in Japan in 1970 (x 10^3 kl/year).

Industry	Heavy oil			
	Class A	Class B	Class C	Total
iron and steel	342	1,476	9,625	11,443
food	514	724	2,021	3,259
textile	148	533	3,997	4,678
pulp, paper	37	266	5,472	5,775
chemical	199	937	11,510	12,645
ceramic	242	1,394	8,710	10,346
nonferrous metals	173	591	1,428	2,193
mining	31	99	269	399
electric power	-	-	35,621	35,621
other	538	1,494	2,584	4,616
total	2,224	7,514	81,237	90,975

Table 2. Consumption of coal by industry in Japan in 1970 (x 10^3 tons/year).

Industry	Coal
iron and steel	55,472
electric	18,826
briquette	2,545
gas	2,339
coke	2,233
fuel for railway	672
ceramic	628
chemical fertilizer	282
general fuel use	2,413
other	2,962
total	88,372

Table 3. Emission of SO_x by industry in Japan in 1970 (x 10^3 tons/year).

Industry	SO_x Emission	Percentage
electric power	1,764	29.5
iron and steel	1,604	26.8
chemical	766	12.8
ceramic	512	8.6
pulp, paper	352	5.9
other	882	16.4
total	5,880	100

Table 4. Consumption of fresh water by industry in Japan in 1969.

Industry	Production (x 10^8yen/year)	Unit of water consumption (m^3/day)/(x 10^8yen/year)	Amount of fresh water (x $10^3 m^3$/day)	Recycling ratio (%)
iron & steel	5,190	294.53	1,528.6	70
food	6,217	71.83	446.6	15
textile	3,864	143.50	554.5	5
clothing	841	8.67	7.3	0
lumber & wood products	1,969	14.07	27.7	10
furniture & fixtures	874	10.86	9.5	6
pulp, paper, & allied products	1,864	791.64	1,475.6	25
printing & publishing	1,757	14.50	25.5	40
various chemical industries	4,836	543.34	2,622.8	60
refining of coal & oil	1,490	157.17	234.2	70
rubber products	703	102.15	71.8	40
leather & leather products	300	32.79	9.8	0
ceramics	2,121	146.17	310.0	40
nonferrous metals	2,574	101.86	262.2	50
metal products	3,062	28.16	86.2	5
mechanical industry	5,285	16.46	87.0	15
electrical machinery	6,103	19.77	120.7	20
transport equipment	6,300	33.63	211.9	55
precision industry	746	16.21	12.1	5
other	2,078	50.67	105.3	0
total	58,175	153.42	8,209.3	45

Table 5. Solid wastes exhausted by industry in Japan in 1970 (x 10^4 ton/year).

Industry	Exhausted solid wastes	Percentage
iron & steel	2,006	34
pulp, paper, & allied products	354	6
chemical	944	16
nonferrous metals	767	13
electrical machinery	885	15
other	944	16
total	5,900	100

Table 6. Reuse of blast furnace slag in Japan in 1971 (x 10^3 ton/year).

road	9,573
roadbed	272
concrete	1,782
fertilizer	413
rock wood	103
cement	1,587
building material	204
blast sand	31
landfill	5,591
self consumption	4,531
total	24,089

material flow in an iron and steel making plant is shown in Figure 1, together with the major pollution phenomena (phenomena such as soil pollution, noise, vibration and odor have been omitted for simplicity). Further, pollution problems from power generating plants and other incidental plants are also omitted.

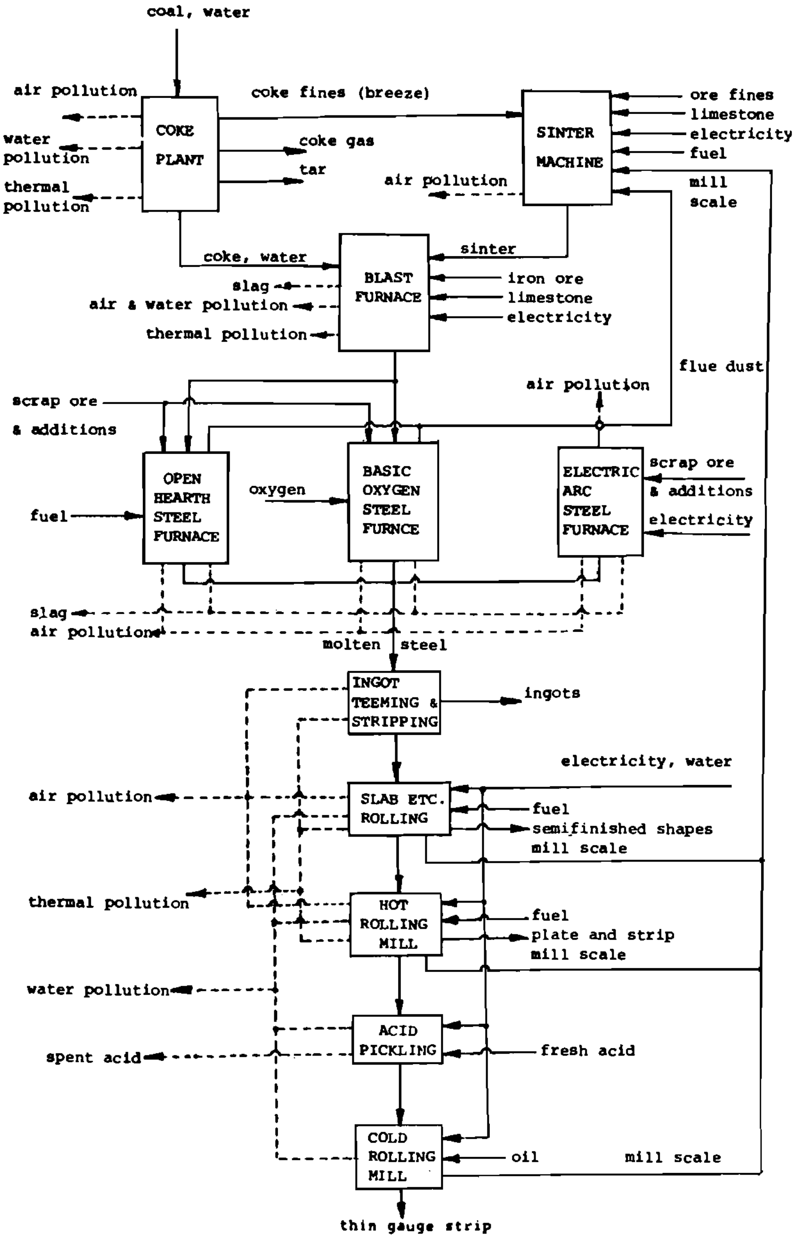


Figure 1. A simplified material flow and pollution phenomena in an iron and steel making plant.

Too, it is necessary to investigate secondary and tertiary pollution phenomena. A typical example of secondary pollution is the water pollution resulting from air pollution control by a wet scrubber. Figure 2 shows the necessity of researching the interrelationships of some types of pollution phenomena from a total systems viewpoint and the necessity of integrating pollution control systems.

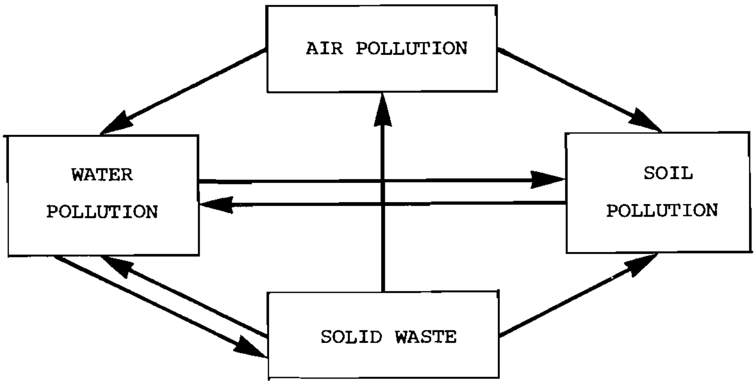


Figure 2. Interrelationships between pollution phenomena.

Next, we must investigate the quantitative input-output relationships for the entire iron and steel making plant. These relationships depend on the size of plant, type of production, level of technology, quality of input materials, and so on. Let me introduce one example of a plant that produces six million tons of steel per year. The rough material flow is estimated as shown in Figure 3, and it is also estimated that energy inputs of 89.6 kl per hour of heavy oil and 2.25 billion kwh per year of electric power are necessary. The estimated fresh water requirement for this model plant is 73 million tons per year.

Based on this flow diagram, we must determine the pollution control policy for each process. This means that we must determine the best pollution control devices and their capacities, together with the necessary investment.

As an example, the distribution of the size of particulates differs in each process, and it becomes necessary to determine the best pollution control devices taking the character of each pollutant into account. Further, we must investigate the problem of efficiency loss resulting from the pollution control device, for example, the pressure loss caused by the air pollution control device, and the necessary, extra amounts of energy and water required to drive the device. All their costs must also be taken into account.

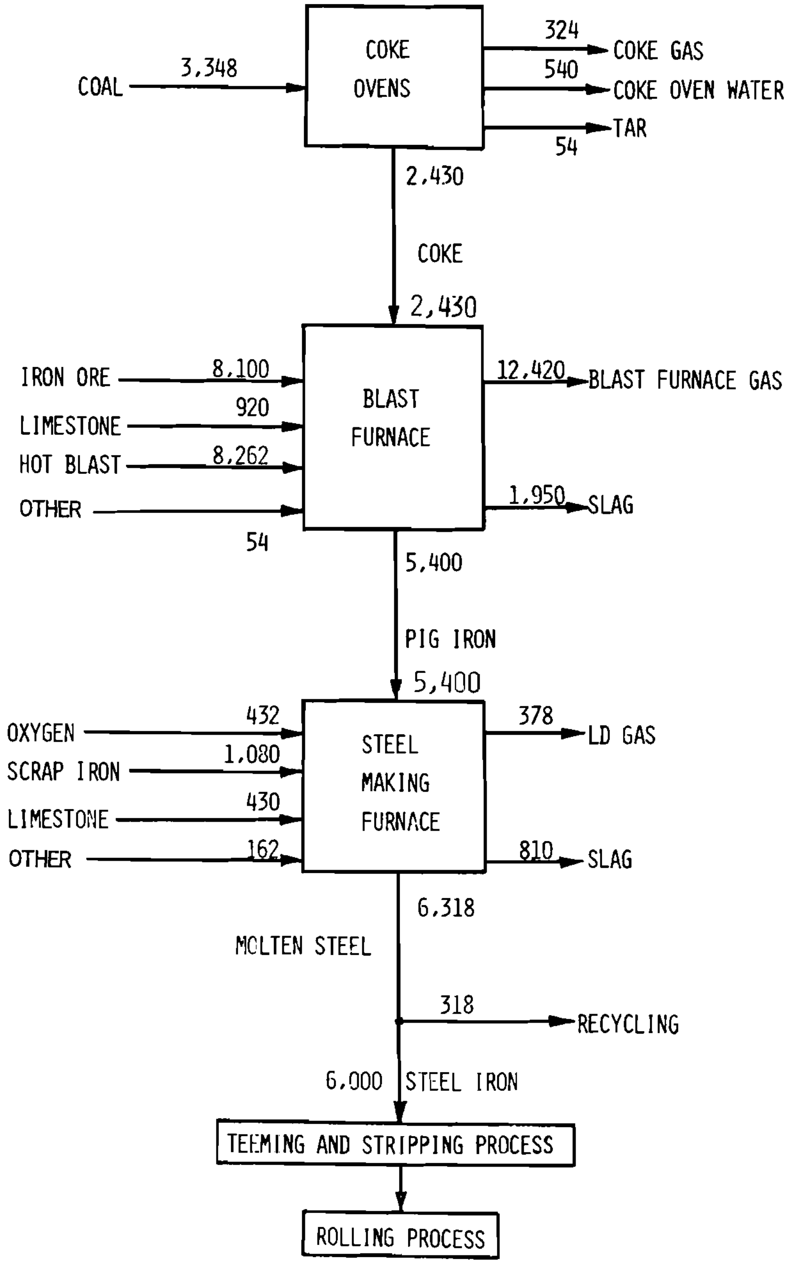


Figure 3. Material flow diagram of a model plant (x 10^3 tons/year).

Generally speaking, as the recent development of pollution control technology has been very rapid, it is not easy to evaluate real effects of pollution control. However, it is important to plan the plant on the basis that modern pollution control devices are adopted.

Figure 4 illustrates a plant in which air and water pollution control devices are adopted for each process. In this figure, pollution control equipment such as dust collectors, stacks, exhaust gas desulfurization, and waste water treatment units are shown. In this research, only the particulates and sulfur oxides of the air pollutants and some aspects of water pollution are investigated, taking pollution control effects into account.

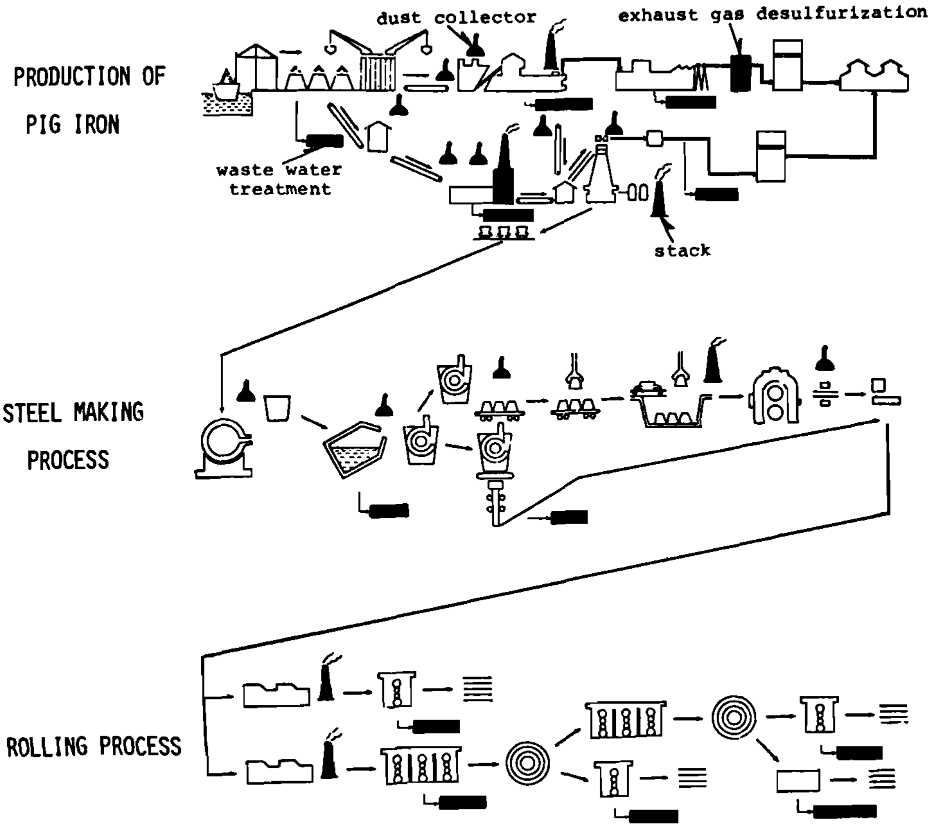


Figure 4. Air and water pollution control equipment in an iron and steel making plant.

Now let us consider some air pollution problems in more detail. Figure 5 shows the amounts of particulates generated at each process together with the amounts exhausted after pollution controls. The relative amounts of particulates are also shown in this figure to make comparisons between processes. Now, if we apply reasonable pollution control devices to the plant, for example, dust collectors that utilize the present level of technology, we can decrease the amounts of pollutants exhausted to the levels shown in Figure 5. A relative comparison of the amounts exhausted at each process is shown in the figure. From this diagram, we can see, for example, that it is easier to control dust in the steel making process than in the sintering process.

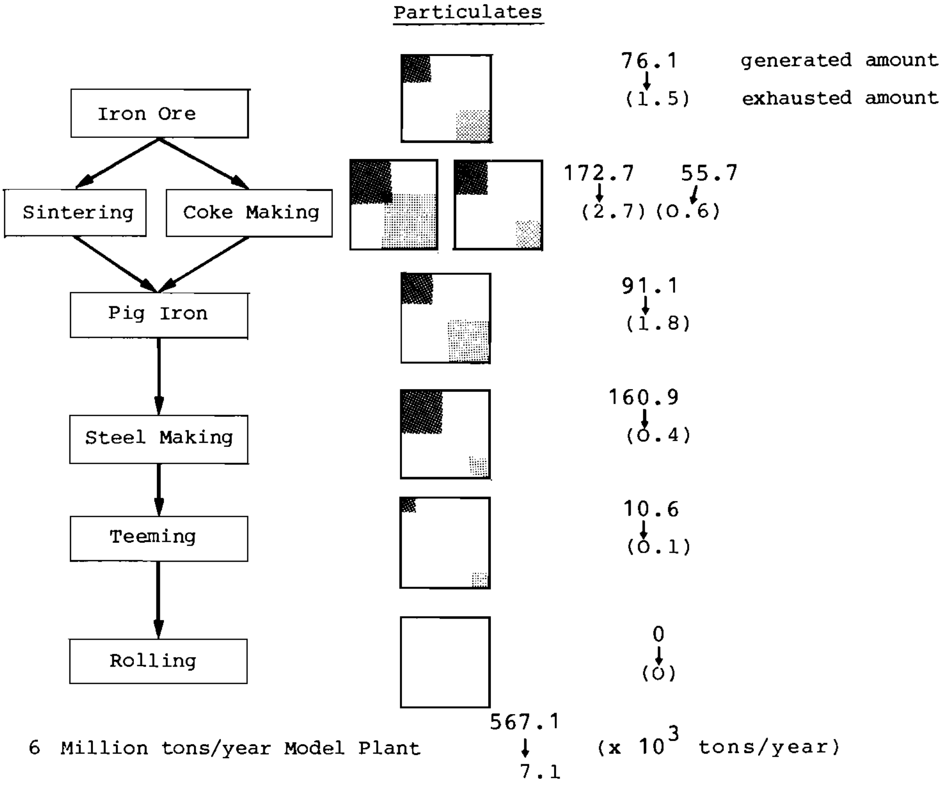


Figure 5. Amounts of particulates generated and exhausted at each process.

Next, concerning sulfur oxides, we can estimate the amount which is generated at each stage as shown in Figure 6. If we install desulfurization equipment that makes use of the present level of technology, we can reduce the sulfur levels to the indicated exhaust levels; their relative relationships for each process are also shown in this figure. At the present level of technology, it is still very difficult to use exhaust gas desulfurization equipment in pig iron production, steel making, teeming and rolling operations, and no pollution control devices are currently used in practice. Therefore, the amounts of generated and exhausted sulfur levels are assumed to be equal.

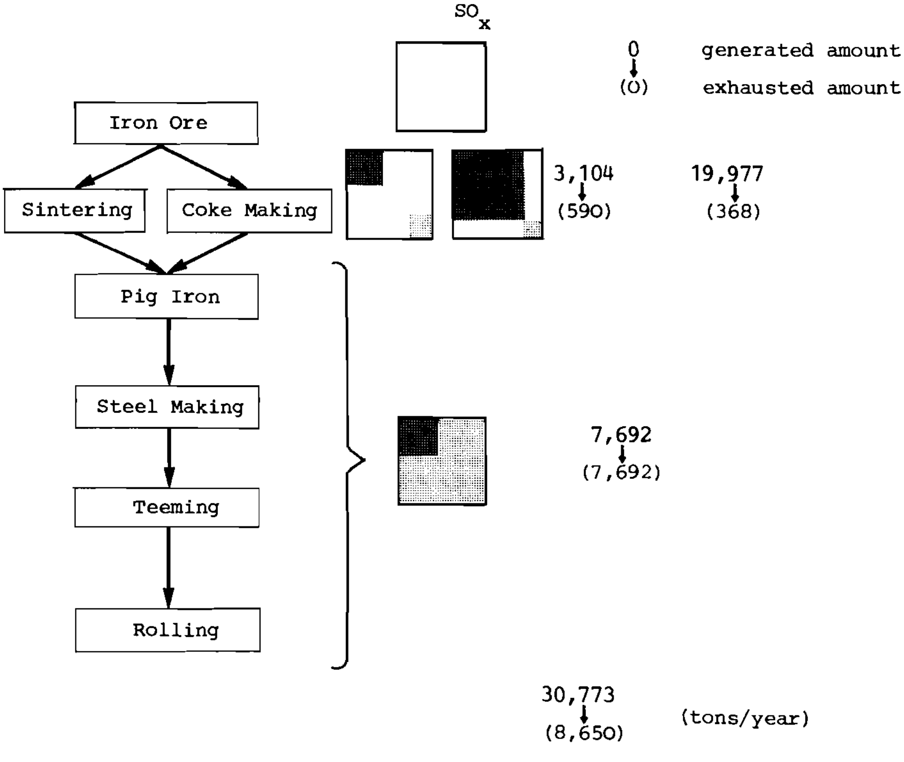


Figure 6. Amounts of SO_x generated and exhausted at each process.

In a similar way, we can look at other air and water pollutants. Table 7 is a summary of air pollution and its control in the model plant, and Table 8 shows the result concerning water pollution and its control in the model plant. Table 8 also includes the secondary water pollution owing to air pollution control by wet scrubbers. As a result of this study, it is estimated that the construction investment for pollution control equipment is 10.9% of the total construction investment of the model plant.

In the past, the investment in pollution control in the iron and steel industry was very low as shown in Figure 7, but recently industry has been making strong efforts to improve the quality of the environment step by step.

Figure 8 shows the effects of air and water pollution control on prices. These estimates were made using input-output analysis; however, these kinds of studies are still in progress, and a great deal more effort must be focused in this direction. Recently, in addition to efforts to develop pollution control technology, it has become necessary to apply modern systems science techniques because of the complexity of the problem.

Not only is the management of the environmental pollution control problem in the iron and steel industry important, but it is also necessary to build recycling systems for scrap iron and steel to conserve natural resources. In Figure 9, the amounts of recycled iron and steel in Japan are shown, and we can see that a considerable percentage of the scrap iron and steel is reused as raw material in the steel industry.

Table 7. Air pollution and its control in an iron and steel making model plant.

Process	Pollutant	Exhausted gas volume (N^{m3}/year)	Pollutant concentration (gr/Nm^3)		Pollutant amount (ton/year)*		Pollution control investment (x 10^6yen)
			input	output	input	output	
iron ore plant	particulate	30,500	5	0.1	76.146	1,523	1,050
coke ovens	particulate	22,200	10-30	0.1-1.0	55,722	571	656
	SO_x	2,000	19	0.35	19,977	368	1,500
sintering	particulate	55,700	1.5-15	0.1	172,744	2,718	1,950
	SO_x	35,600	250(ppm)	25(ppm)	3,104	590	8,000
pig iron	particulate	68,000	0.2-5	0.1-0.1	91,135	1,827	1,460
steel making	particulate	30,000	5-80	0.1	160,874	449	3,150
teeming & pouring	particulate	8,500	5	0.05	10,610	106	270
total	particulate	214,900	0.2-80	1.01-1.0	567,231	7,194	8,536
	SO_x	37,600	19	0.35	23,081	958	9,500

*The amount of sulfur oxide is calculated by the weight of sulfur.

Table 8. Water pollution and its control in an iron and steel making plant.

		Amount of waste water (tons/day)	Suspended Solids				Waste oil				Other			
			(ppm)		(tons/year)		(ppm)		(tons/year)		(ppm)		(tons/year)	
			input	output	input	output	input	output	input	output	input	output	input	output
iron ore plant		14,250	7,500-8,500	40	41,610	208								
blast furnace		63,130	1,000-4,000	40	57,606	922								
coke ovens	direct waste water	1,200	100	40	44	18	50-200	0-10	55	2	CN:100-150,phenol:1,500-2,000	CN:1 phenol:1	CN:55 phenol: 767	CN:0.4 phenol: 0.4
	wet scrubber	16,150	7,500-8,500	40	55,918	280								
pickling coating		36,000	30-600	40	4,145	464	500	0-10	5,475	55	HCl:100-1,000, CrO_3: 5,000-10,000	HCl:0 CrO_3:2	HCl: 8,432 CrO_3: 16,426	CrO_3:4
teeming and stripping	direct cooling water	30,000	300	40	3,285	438								
	wet scrubber	3,670	7,500-8,500	40	10,716	54								
other		16,740	2,500-3,500	40	18,330	244								
total		184,140	2,500-3,500	40	201,633	2,688			5,530	57			CN:55 phenol: 767,CrO_3 :16,426, HCl: 8,432	CN:0.4 phenol:0.4 CrO_3:4

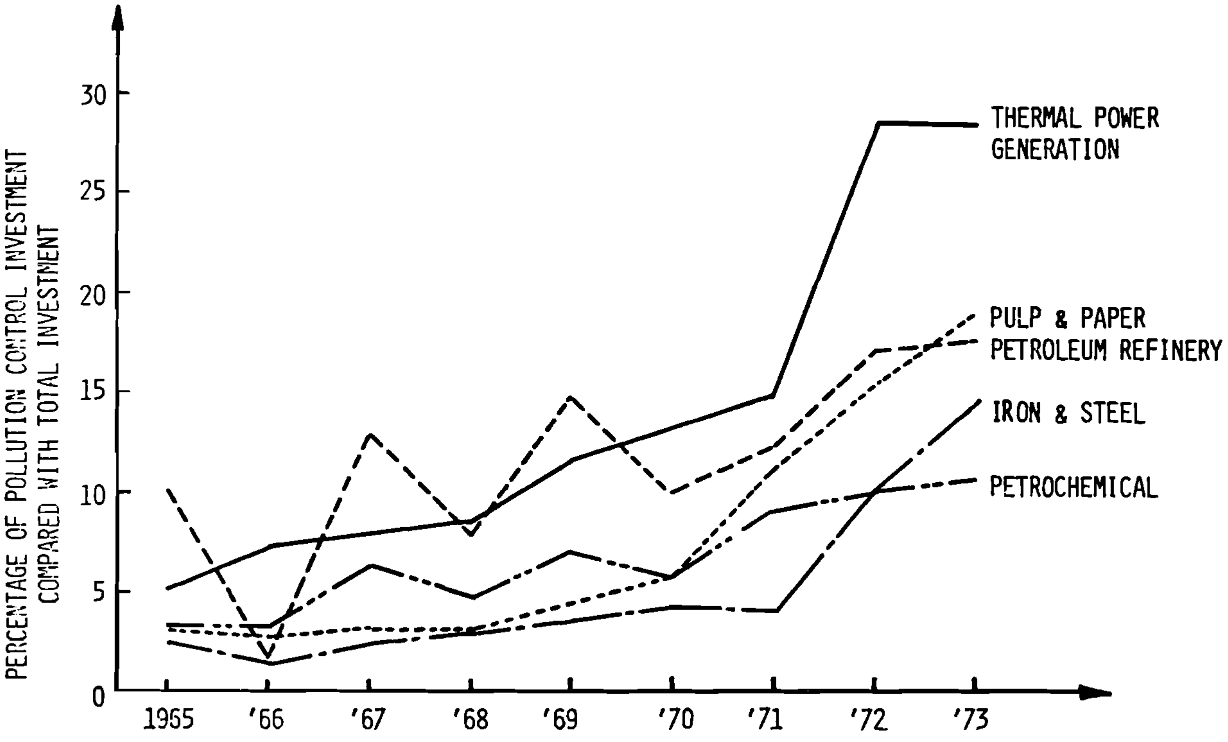
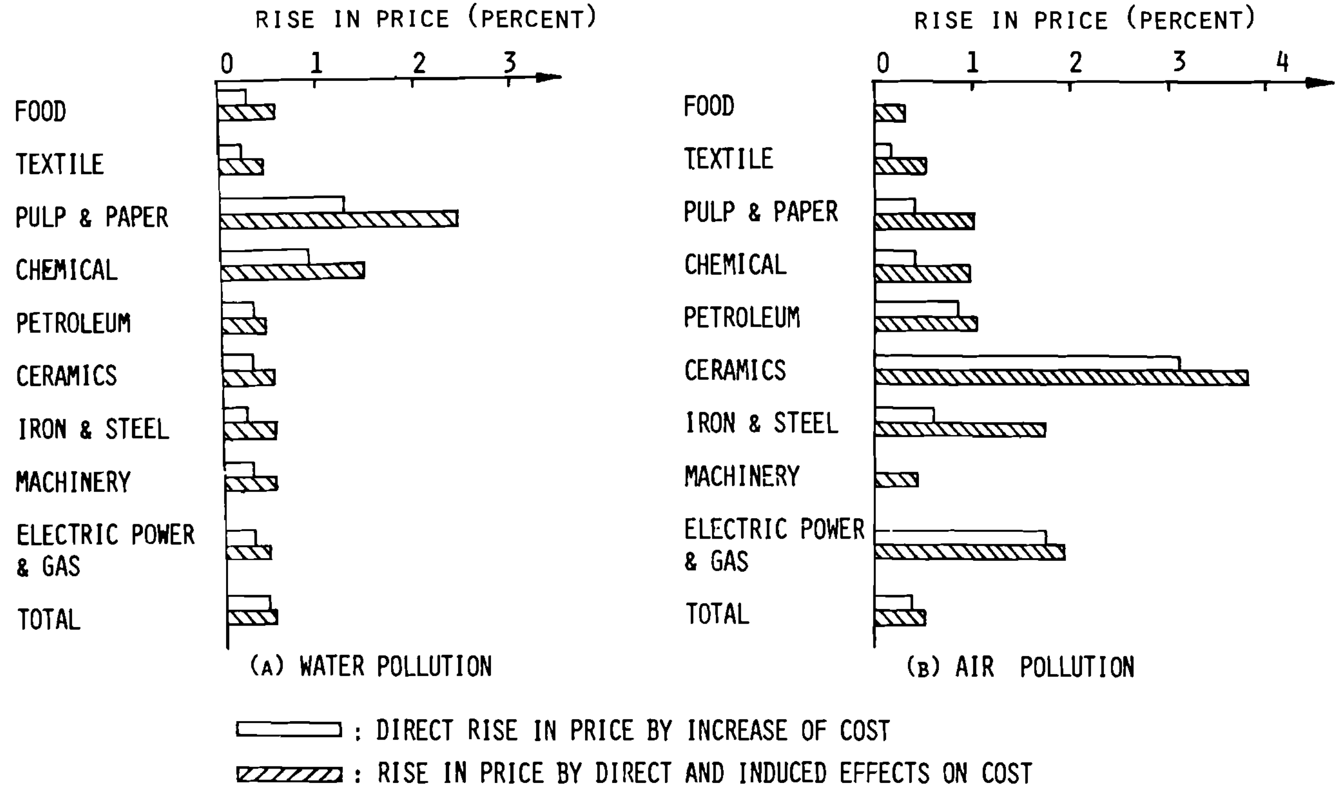


Figure 7. Pollution control investment of large enterprises in Japan.



Note: Induced effects on cost are estimated using I-O analysis.

Figure 8. Effects of pollution control on prices.

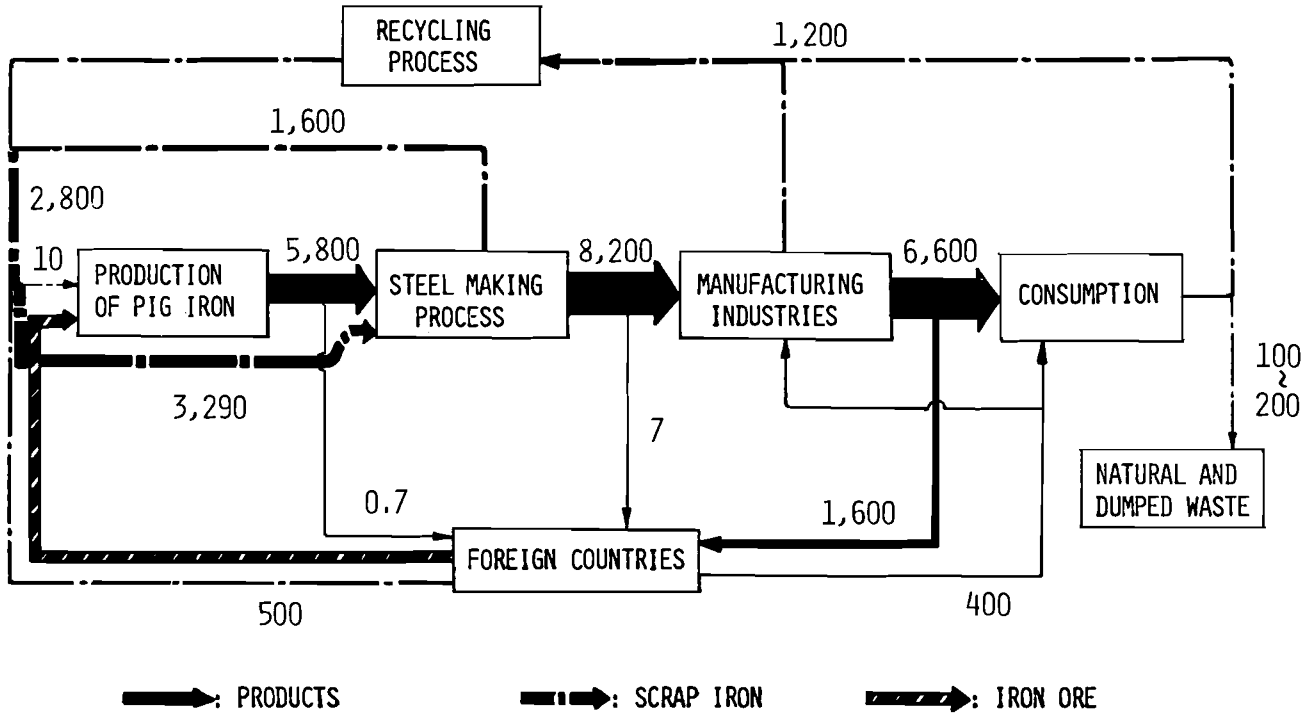


Figure 9. Recycling system of iron and steel making: Japan, 1969 (x 10^4 tons/year).

Discussion

Mazel

Thank you very much Mr. Ito for this information. The pollution problem is a very new view for many of us and it is very important to the problem of systems integration. It is now time for discussions of these papers.

Lefkowitz

I wonder whether Messrs. Ito or Sawaragi can say anything about specific ways that the imposition of environmental constraints affect the planning, scheduling, and control problems as they are applied in the iron and steel industry. Are there specific instances, either current or projected for the immediate future where the consideration of these constraints is expected to play an important role in the design of the integrated systems control?

Sawaragi

Our project relates to rather academic interests in environmental pollution control. Almost all the members of the project team are academic scientists from the faculty of engineering. Therefore we have done no research work on the practical aspects of planning, designing, and implementation for industry. Hereafter, we would like to cooperate with industry based on the results from research projects like ours.

Lefkowitz

My question is motivated by the fact that in certain areas of the United States, environmental constraints have a direct influence on industrial operations. For example, some power generation industry areas with severe smog pollution problems have a pollution monitoring system so that when the pollution level gets too high the various industries, for example power generating stations in the area have to respond in a way to reduce the pollution level. This may require shutting down a processing unit, or changing its mode of operation or changing from a high sulfur fuel to a low sulfur fuel. But this therefore has a very direct and significant effect on industry's operations and on the design of their information and control systems.

Ito

We are already applying the same system, particularly in the Osaka and Mizushima regions in Japan. There are some large industrial complexes, including iron and steelworks, operating in the Mizushima region, and as you have said, when the environmental quality drops below the standards set by law, the monitoring system catches it, and the control station feeds back the information to the company to change the quality of the fuel or to shut down the production plant. In 1970 the Japanese government passed 14 laws concerning environmental quality; as a result, one steel company, Kobe Steel, had to stop operation of its Kakogawa No. 2 blast furnace until the pollution control problem was settled. I think we are surely applying the same pollution control system elsewhere in Japan.

Long

Do you take into account, in these analyses, the effects of atmospheric conditions, weighing, in a sense, the danger of using one fuel over another against, say, the danger of an inversion in the atmosphere? I wonder whether, theoretically, some risk analysis has been carried out.

Ito

I think risk analysis is very important, and sometimes more important than the underlying pollution problem. A typical example is the accident that happened last December in the Mizushima area in Japan where an oil tank in a refinery blew up and heavy oil dispersed out to the ocean. Some people now think that it will be impossible to catch fish in that region for 30 years. So, I think that environmental pollution problems are very much connected with risk problems.

Relevant to the risk problem, the government of Japan has decided to support research in the application of atomic energy to the iron and steel industry and the problem is now becoming one of the special national research projects.

Cheliustkin

Kelley and I visited several Japanese steelworks, and we were told that, depending on the metereological conditions, the production of a sinter plant may be reduced to decrease the pollution level. Thus the production planning and scheduling of the steelworks must be carried out considering this possibility.

Plant Maintenance in the Iron and Steel Industry: Highlights in Systems Control

J. Wolfbauer

INTRODUCTION

A considerable part of the expenses in a steel plant are for plant maintenance (see Figure 1). Hence, in discussing systems control in the steel industry, it is necessary to consider some aspects of maintenance of the production system.

	Maintenance C. (DM/t, 1973)	% of Operating C.	% of Total Cost	
PIG IRON	9.-	35	5	
BOF STEEL	6.-	17	2	Dev.± 20%
ROLLING MILL PRODUCTS	15.-	20	4	
IRON AND STEEL PRODUCTS	32.-			

SPARE PARTS	6 - 10 % of Fixed Assets
MAINT. MANPOWER	18 - 35 % of Total Plant Manpower
MAINT. LABOR COST	40 - 70 % of Total Maintenance Cost

Figure 1. Cost figures and indices of plant maintenance in the steel industry.

These figures show that approximately 50% of the expenses for maintenance are connected with the chemical processing phases of iron and steel production and the rest with the shaping of steel to produce saleable products.

One key area for savings--or a primary goal for system's control in the field of maintenance--is the control of manpower. But in this area, especially, the requirements for maintenance personnel in steelworks vary over a broad range.

The reasons for these differences might be:

- application of different methods in planning and systems control;

- different points of view on risk situations related to maintenance.

To get a clear picture about the pluses and minuses of various methods of systems control in plant maintenance, it is necessary to analyze the maintenance with respect to:

- structure of the system,
- objectives and evaluation of performance,
- environment,
- planning, scheduling, and control functions.

BASIC PLANT SYSTEMS: MAINTENANCE

Plant maintenance can be described as a subsystem of the production system. The primary means (input) of production are material, manpower, and equipment. For maintenance purposes, equipment represents "wearing supply" (see Figure 2) which decreases during production.

Equipment wear is the predominant environmental input to maintenance. Plan maintenance tries to match this wear by various types of responses:

- replacement of "wearing supply" (for example, repair),
- preparedness--preventing secondary wear out, preventing downtime costs.

Evaluation of Performance

The input to realize maintenance performance is readily measured in terms of actual maintenance cost. But it is difficult to measure parts of the output or to evaluate the correlated performance. Performance of preparedness-type maintenance should be measured against the costs of the prevented events; however, this is speculative, for there is no exact basis for evaluation. The individual value margins used by management cause very different risk expectations which are reflected, for example, in the allocation of more or less manpower for preparedness purposes. Therefore it is not efficient to control maintenance like a profit center.

Minimal Cost Policy

Looking at a very formal and abstract cost model of plant-maintenance (see Figure 3), the level of planning and control can be considered the independent variable of the system. Costs

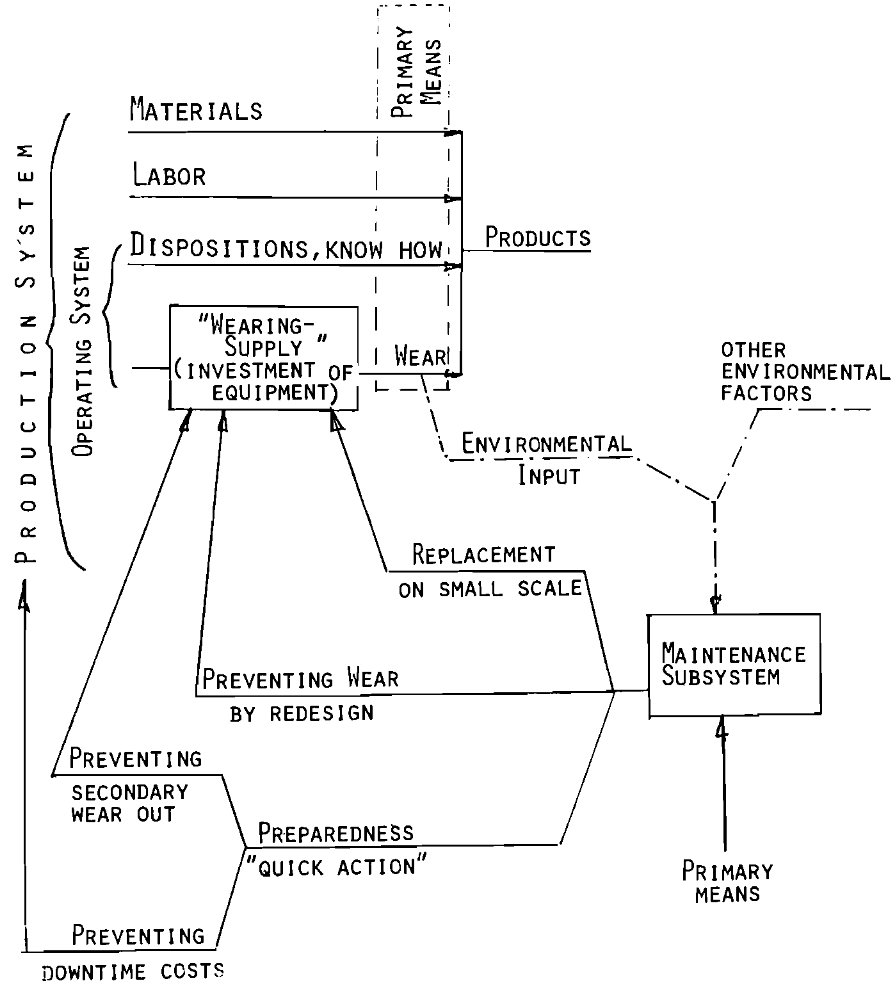

PRIMARY MEANS
MATERIALS
LABOR
DISPOSITIONS, KNOW HOW
PRODUCTS
PRODUCTION SYSTEM
OPERATING SYSTEM
"WEARING-SUPPLY" (INVESTMENT OF EQUIPMENT)
WEAR
OTHER ENVIRONMENTAL FACTORS
ENVIRONMENTAL INPUT
REPLACEMENT ON SMALL SCALE
MAINTENANCE SUBSYSTEM
PREVENTING WEAR BY REDESIGN
PREVENTING SECONDARY WEAR OUT
PREPAREDNESS "QUICK ACTION"
PRIMARY MEANS
PREVENTING DOWNTIME COSTS

Figure 2.

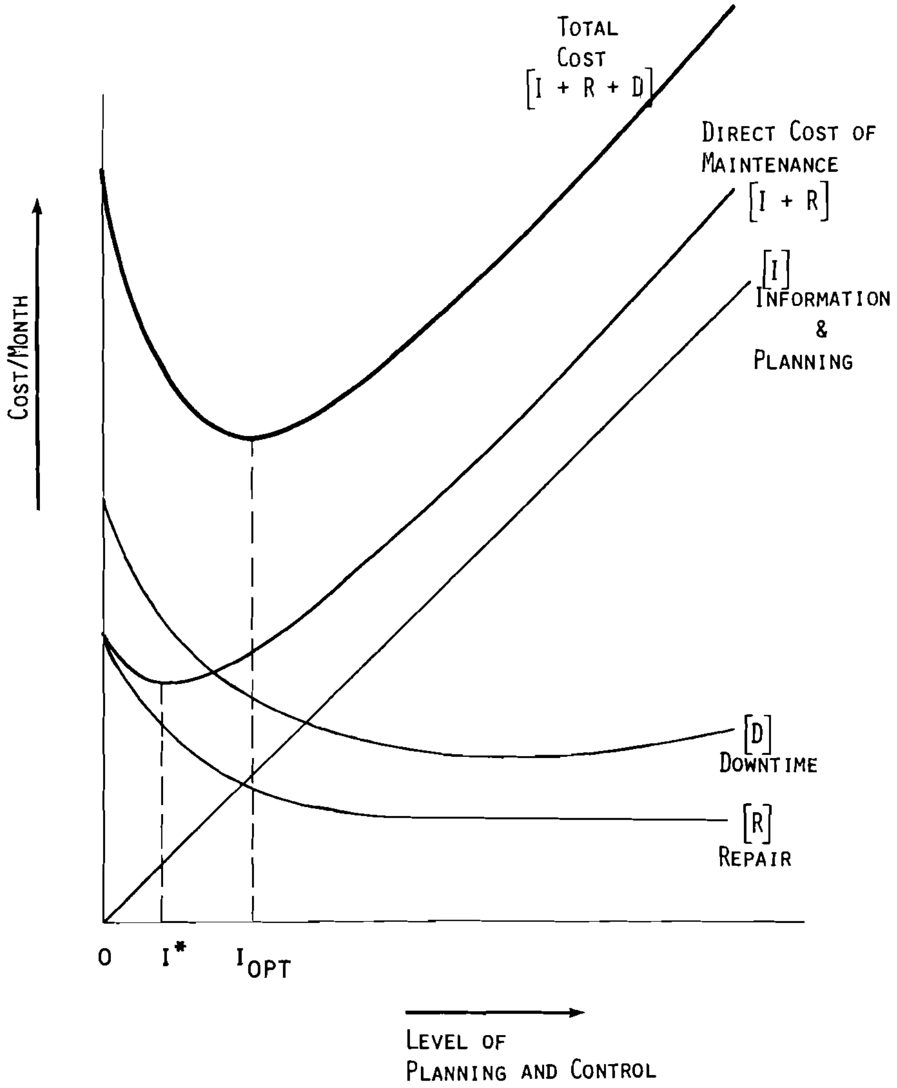


Figure 3. Abstract cost model of plant maintenance.

associated with the level of control (I) are assumed proportional and linear. The level of control affects the cost of repair (R) and the cost of downtime (D). A minimum level in the direct cost of maintenance (I + R) is reached at the control level I* (Figure 3), and a minimum total cost (I + R + D) is reached at I_{opt} (see Figure 3).

Investigations of existing operating systems of control in plant maintenance (see Figure 4) show the cost associated with the level of control to be nonlinear. Only systems control at an advanced level causes a decrease of total cost. However, these models provide only qualitative guidance for systems control. The cost function of the models is known quantitatively only over a very small range.

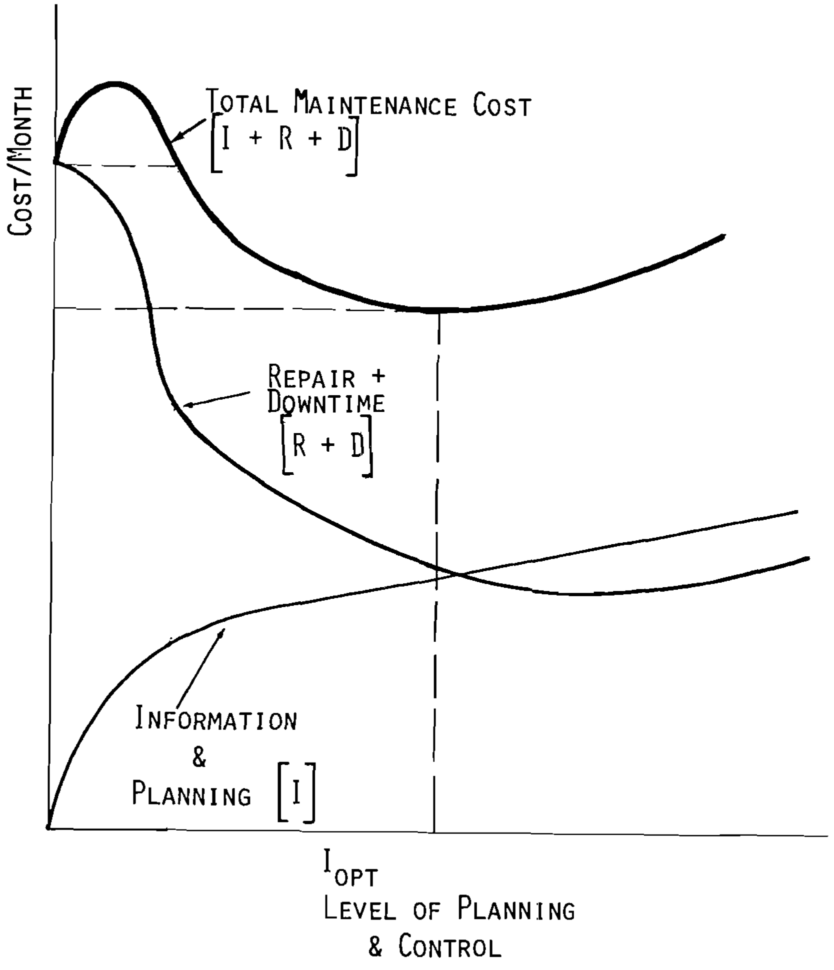


Figure 4. Actual cost model of plant maintenance.

Objectives

If maximum profits and minimum costs are nonfeasible objectives, a more common objective, adequate availability at minimal cost, should be useful. This objective is suitable for nearly any applied method, and, to apply it, it is necessary to define a series of sectoral objectives which correspond to the different applied methods (see Figure 5).

METHOD	OBJECTIVES
OPTIMAL TIMING OF MAINTENANCE JOBS	(1) PREVENT BREAK DOWNS (2) PREVENT SECONDARY WEAR OUT
MODERN ENGINEERING	(3) MINIMAL COST JOBS (4) MINIMAL TIME FOR MAINTENANCE JOBS
DESIGNING OUT MAINTENANCE	(5) INCREASE LIFETIME (WEARING TIME) OF PARTS & (2) , (4)
WORK PLANNING & SCHEDULE	(6) OPTIMAL LABOR UTILIZATION & (3) , (4)
DISPOSITION OF MANPOWER	(7) GUARANTEE PREPAREDNESS & (6)
DISPOSITION OF SPARE PARTS	(8) MINIMIZE DEAD CAPITAL & (4) , (7)

Figure 5.

Implementation of Plant Maintenance

To operate the methods and achieve the objectives in plant maintenance, we establish an organizational frame which delineates the

- structure of competence and responsibility, and the
- general disposition of the work force and spare parts.

These sectors of organization correspond to the following hierarchy of time horizons:

- long-range planning (for example, five to ten years) for the structure of competence and responsibility;
- medium-range planning (for example, three months to two years) for the disposition of the work force and spare parts;
- short-range planning (for example, up to six weeks) and control (for example, from real time to two or three days) are represented by a number of facilities to plan and control, such as
  - monitoring equipment,
  - work planning, scheduling, and supervision,
  - costing,
  - key figures and statistics,
  - inventory control.

The individual maintenance systems differ on a broad scale as different quantitative combinations of environmental constraints are possible.

These environmental constraints may be:

- applied technology in production and maintenance methods,
- requested cycles of equipment-availability,
- breakdown losses,
- size of plant and design,
- location (infrastructure),
- market situation.

The impact of this environment on the structure of a plant maintenance system makes it necessary to discuss these parameters more intensively.

PARAMETERS FOR MAINTENANCE IN IRON AND STEEL PLANTS

Applied Technology in Production

I intend here to present only a few of the relevant factors for the design and layout of a suitable maintenance system as follows:

- The specifications and frequently even the pilot design of equipment give no information about adequate maintenance control at the time of starting. In contrast to this, in mechanical engineering plants, information from similar equipment already in use supports effective maintenance planning and control.

- Many changes are introduced through redesign during the rather long lifetime of the plant to match performance of new and competitive equipment. This makes it almost impossible to get significant figures of wear out functions.

- The chemical processing stages in the production of iron and steel involve heat, dirt, and other extreme conditions that effect often unknown changes in wear. These facts are an obstacle to run a periodic preventive maintenance control system.

- The state of wear out is recognizable in most cases. Hence if an adequate monitoring and inspection system is in use, on-demand repair can be converted to planned repair. Analysis shows 85% to 95% of the maintenance jobs in the iron and steel industry to be repetitive jobs. This makes it suitable to use job plans and to intensify on-demand-planned repair. In some cases, processing know-how is to be protected and in-house repair is preferred.

Requested Technology in Maintenance

At least 50% of the workload represents simple standards corresponding to common skills of craftsmen. The use of outside repair personnel is possible on a broad scale. A basic requirement for effective control of external repairs is the job plans.

Requested Availability

For this purpose availability can be described as a defined length of time that a given piece of equipment can be expected to operate at average performance without breakdowns or decrease of performance. Normally this period coincides with:

- the lifetime of the major elements of a plant facility (for example, lining of BOF converter); or
- processing cycles (for example, one or two shifts/day); or
- minimum time to arrange planned jobs within an on-demand policy (for example, postponement of execution to the next day using day shift craftsmen, prepared tools and spare parts).

Obviously, there is a handicap in iron and steel processing where the requested availability may range from a minimum of 20 hours to several weeks, compared to the mechanical engineering industry where availabilities may be only eight to sixteen hours and where there are typically alternative paths within the workshop.

Breakdown Losses

Breakdown losses in iron and steel plants are high, but they still would not pay for duplication of main equipment. Breakdown costs (see Figure 6) combine:

- Costs of unused consumption of primary means during breakdowns (for example, idle operators, energy in furnaces). These are costs that are dependent on the duration of the breakdown, the structure of material flow--especially intermediary supplies and bypasses, and the switch-off policy.
- Lost profits. They correspond to requested capacity lost in breakdowns or decreased by equipment wear out. It depends on the total breakdown time and the market situation within medium range planning.

The amount of breakdown losses does not indicate the adequate overall maintenance costs, but it is a very useful yardstick to evaluate changes in applied maintenance methods.

Size of Plant and Design

Equipment in the iron and steel industry usually consists of large in-line capacities. Medium or large plants prepare for maintenance predominantly with manpower. They are able to handle the more or less stochastic peaks of demand for maintenance, caused by a large number of shops, with an almost constant manpower capacity from a central pool. Small plants are forced to match the few and random peaks of requested maintenance

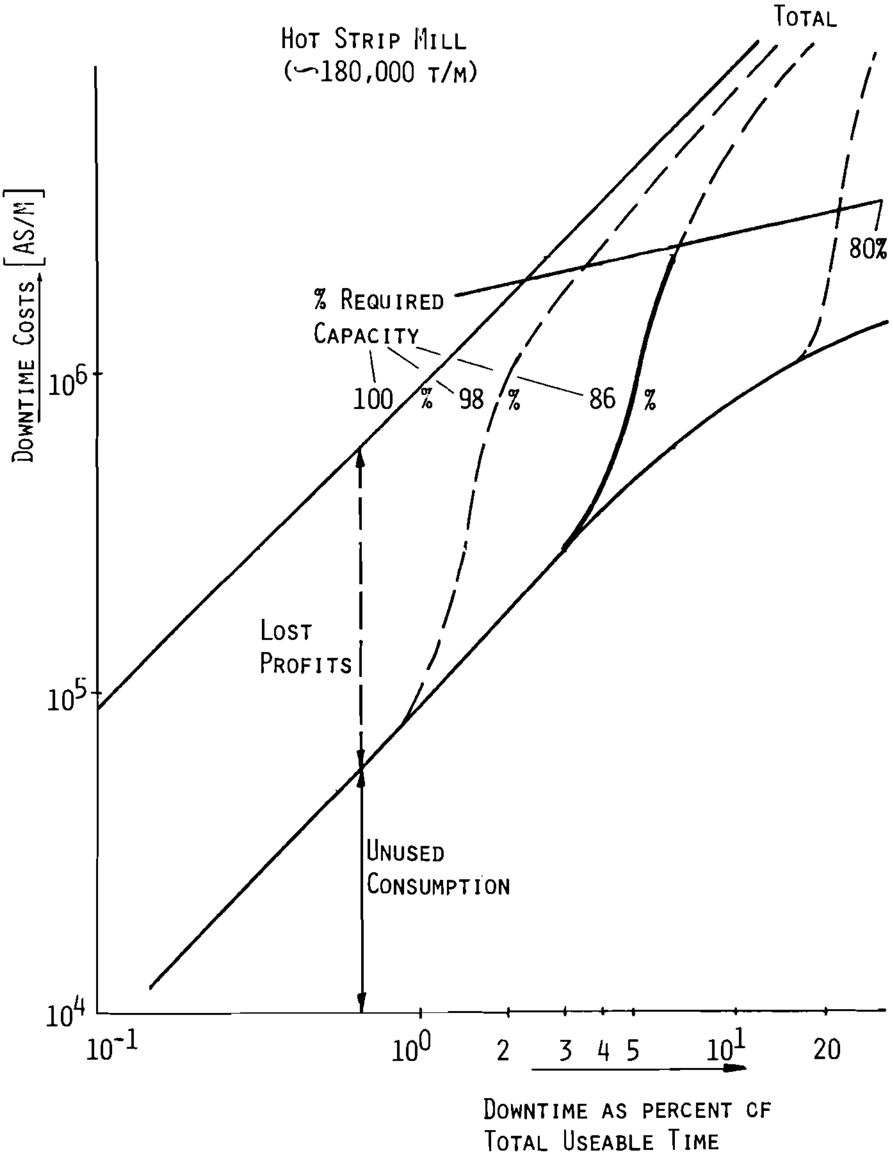

Hot Strip Mill
(∽180,000 t/m)
Total
Downtime Costs [AS/M]
% Required
Capacity
100 %
98 %
86 %
80%
Lost
Profits
Unused
Consumption
10^6
10^5
10^4
10^{-1}
10^0
2
3
4
5
10^1
20
Downtime as percent of
Total Useable Time

Figure 6.

with more emphasis on equipment preparedness (for example, bypasses, redundancies, spare parts), and that means more investment and more fixed capital.

Location

If the plant is located within an industrial area, outside repair should be easily available. Contracts for services by highly skilled specialists are effective for local areas.

Market Situation

The iron and steel industry is the leading business with cycles of four to six years. Superimposed on these are seasonal variations. If no other constraints exist, the changing demand in manpower can be met with outside service companies.

KEYPOINTS IN SYSTEMS CONTROL

Systems control in plant maintenance generally consists of activities such as (see Figure 7):

- monitoring and inspection of equipment,
- planning, scheduling, and control of jobs,
- inventory control,
- costing:
  - control of deviations,
  - budgets,
  - evaluation of downtime.

Value analysis shows the impact of these controlling activities on the objectives of maintenance. The high-lights are shown in Figure 7.

About two-thirds of the activities concern information processing, and the remaining third concerns execution of functions control. More than half of the activities--monitoring equipment, job planning, and control--are done by the maintenance staff. A very sophisticated inventory control is not important here.

These subjective values were focused on a sample of maintenance control (see Figure 8) which show the profiles of operating standards in several activities of maintenance control.

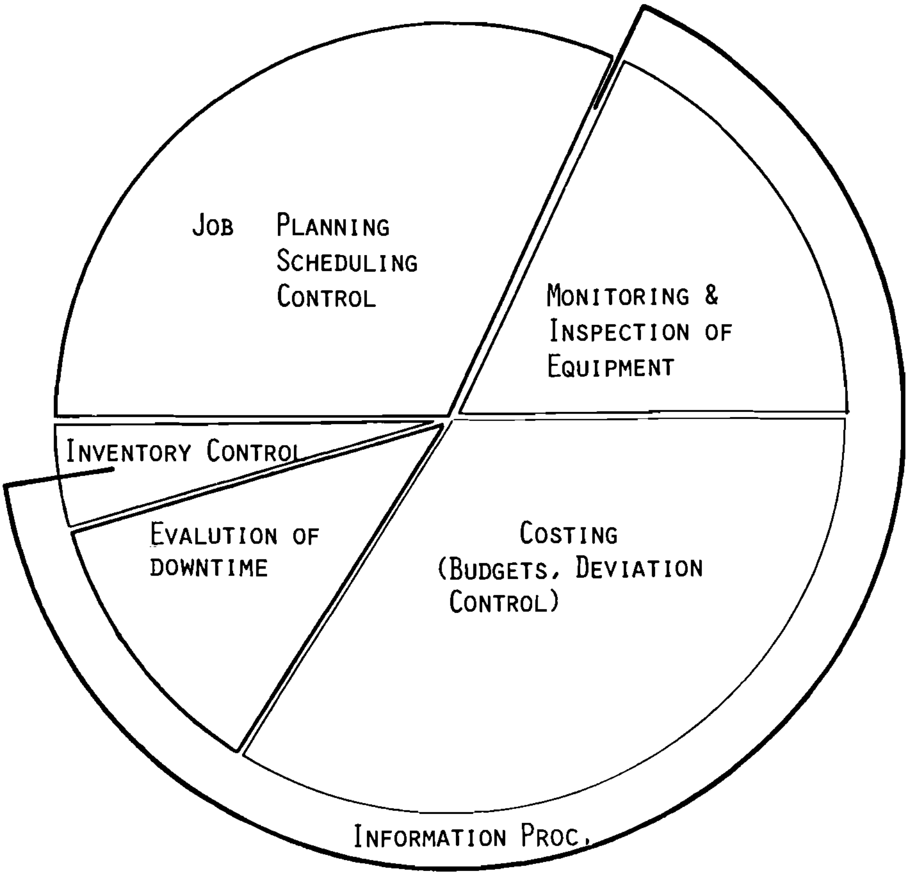


Figure 7. Sectors of effective planning and control in maintenance.

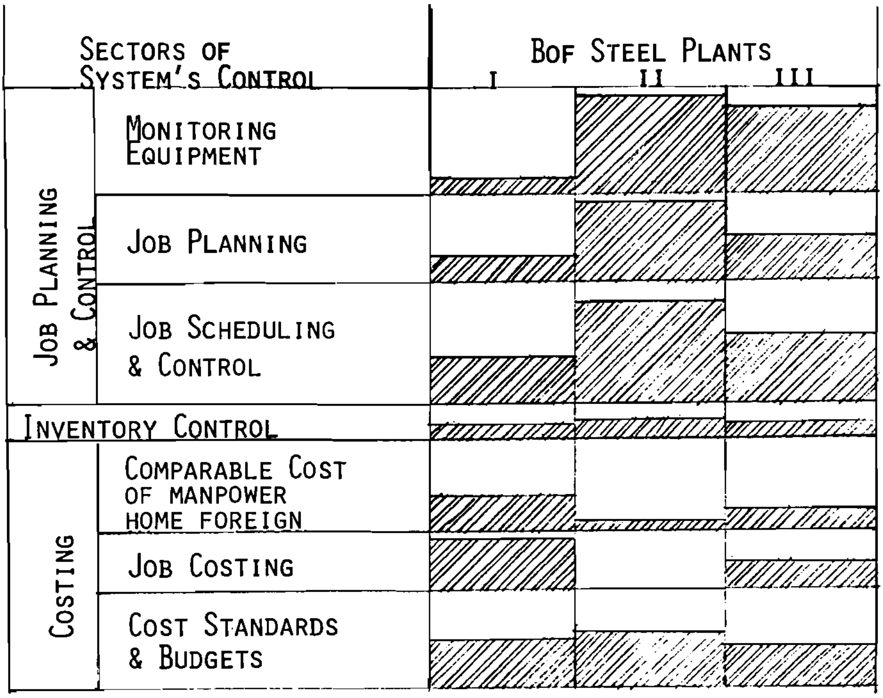


Figure 8.

State of the Art

Applied technologies in iron and steel plants are blends of chemical and mechanical engineering processes. Their special operating conditions cause unknown wear and, consequently an unknown input to maintenance (see Figure 9).

Technological Process Type

Chemical	Mechanical Engineering
100%	400%

Δ	Δ
Blast Furnace	Cold Milling

Unknown standard for control
Random wear mix
  Heat
  Dirt
  Overlaid Strain

Figure 9.

Breakdown losses are not yet used for planning purposes. This fact is to be considered an ignoring of economic constraints. Research here has already started, but it will take about two years until breakdown losses can be used as a factor for planning and control maintenance. Computer-aided maintenance control has been applied successfully to run periodic jobs in the mechanical engineering industry. Systems to control on-demand jobs are in preparation. They will provide on-line systems with dialogue capabilities.

Short-Range Activities

To increase the effectiveness of systems control, a multilayer modification, corresponding to specific quantities of environmental mix, should be created. An objective is the determination of a feasible ratio of periodic to on-demand maintenance jobs and the increase of the fraction of on-demand jobs that are planned. This would cause a feedback to periodic jobs such as inspection and monitoring of equipment. All this can be performed with already known and commonly used methods. The key point is to increase the motivation to apply systems analysis to the individual environment of each mill within the plant.

Medium-Range Research Projects

Correct systems control is based on knowledge of systems behavior. Therefore the still unknown input-output relationships between intensity of production, wear out of equipment, and quality of maintenance should be investigated. Particularly, the effect of the ratio of different maintenance activities on equipment availability should be analyzed. These changes should be related to downtime cost; therefore, downtime cost should be analyzed and recorded individually for each plant facility.

With these results it should be possible to match changes in requested availability caused by changes in the market situation through an optimal maintenance mix. For example, in a depressed market, risks for breakdown losses are low and preventive maintenance activities may be reduced; in boom situations the relationship might be reversed.

Long-Range Perspectives

The plant maintenance system results in the collection of considerable operating data and experience which should be useful in the design phase of new equipment. By this feed forward, plant maintenance can fulfill an important role within equipment management.

Appropriate equipment management consists of:

- providing optimum plant capacity (design and investment);
- controlling the wear out of equipment according to planned equipment life and breakdown risks (plant maintenance);
- reacting to market and technological changes by means of a flexible performance capability (performance adaption).

Plant maintenance is related to design and investment by the already named feed forward of experience and also by controlling depreciation through the policy on repairs. The link to performance adaptation is the impact on equipment availability. In this way, systems control of plant maintenance in the iron and steel industry will become an essential instrument of equipment management.

Discussion

Cheliustkin

I would like to ask why you consider only the cost of equipment downtime and do not consider the loss of efficiency through equipment wear.

Wolfbauer

It was a problem of time for the presentation. If we go into details, I can show you examples. We made such an investigation of a blast furnace in the FRG, and it was very interesting. Here I noticed that the level of maintenance control affected the capacity of the furnace, which had the same overall effect on the performance of the production system as downtime.

Cheliustkin

My second question concerns the model you spoke about. This is a model of one technological unit, but you must also consider sets of technological units working in series or in parallel.

Wolfbauer

You see, the example I considered had not just one point of possible failure, but several points and the downtime costs correspond to the total downtime of the plant. We investigated the effect on downtime of the various possible failures (for example, crane, slab grade, roughing mill, finishing mill, etc.) and the result shown is the total downtime costs.

Phaff

Mr. Wolfbauer, regarding your figure of the breakdown costs of the hot strip mill, if you have a breakdown, you do not necessarily lose sales; you lose delivery time, depending on the utilization of your plant.

Wolfbauer

Yes, downtime not only has an impact on maintenance, it also has an effect on the stock levels of semifinished products. If you have a lot of downtime, you must start the production process earlier and operate with larger inventory costs and that is expensive and should also be connected with downtime maintenance costs. Is this your question?

Phaff

No, maybe I am wrong, but it seems to me that you do make the same sales but you cannot make the delivery.

Wolfbauer

Yes, but in the next planning period you do not take in so many orders. You must say no, I am not able to deliver a new order, and that decreases your capacity, in fact.

Phaff

If you want to have 100% capacity all the time there seems to be no thorough planning.

Wolfbauer

No, it is a market function. It is only a question how much can I do, how many sales can I make, and then I will look at what is my capacity. Is it less? It is too much? If it is less, then the overburden of the sales would be constant for a long time. I can make an investment and you will see the feedback to investment with a good maintenance system.

Toeglhofer

What do you think about the importance of a kind of feedback from maintenance to design and construction? I think it is often very important to use the experiences of maintenance in designing.

Wolfbauer

This problem is under intensive discussion, but I do not know the effect. The effect is really good if the user of the plant facilities is also involved with the design of a similar facility and he is selling his know-how and hardware. Here I know they have no feedback, and it is very necessary. In practical work, it is a problem of information, that is, to get the right people around the table.

Kopetz

On the three steel mills that you examined, what was the relation of on-call maintenance to preventative maintenance?

Wolfbauer

The first result was about 90% on-demand or on-call maintenance, and almost nothing for preventive maintenance. Preventive maintenance is not the right term. They aid almost nothing in monitoring and inspection, and information processing and control processing are very connected in this area. You only talk about preventive maintenance if you go out and look, but you do not prevent anything. The action prevents exactly the wear out or breakdown and that 10% represents periodic works, fuel control, etc. The second result had about 80% planned maintenance, but of this, about 10% was on-demand planned, and only 10% periodic in the sense of preventing things. There is a question of what is a preventive job, that is, if you replace the right thing at the right time is it preventive? It is not easy to say which breakdown costs you prevent by doing this. In the third result, there was a mixture of about 30% emergency maintenance, 20% information and periodic maintenance and 50% for the rest. But the question is, is it economic to have so many people doing periodic things?

Application of the Hierarchical Multilevel Concept to Integrated Control Systems in Machine Building

J. Hatvany

THE HIERARCHICAL APPROACH

I. Lefkowitz has defined the salient features of the multilevel hierarchical approach to the analysis of complex systems as:

- decomposition into a number of coupled subsystems,
- decomposition of decision making into a set of subproblems distinguished with respect to time scale,
- approximation by simplified and aggregated models.

DECOMPOSITION INTO SUBSYSTEMS

In the mechanical engineering (or, in European terminology, the machine building) industry, it has become axiomatic over the past 15 years that it is impractical to proceed by first designing completely integrated manufacturing systems and then going on to build them. The discrete and highly heterogeneous nature of machine part production and assembly operations, the complexity of work flow organization with part types often running into hundreds of thousands, and technological routes having to be uniquely determined for every part, have made the preparation of overall integration plans prohibitively costly and cumbersome and the likelihood of their smooth implementation and operation very small. The method that has therefore been adopted in industrial practice has been the autonomous subsystem approach.

The philosophy of the autonomous subsystem approach has been to design and implement subsystems of the future integrated complex system, in such a way that they are able to function autonomously until such time as they can efficiently be integrated with one another. This strategy then permits the integrated manufacturing system to be assembled from a set of tried and tested subsystems, each of which is implemented, debugged, and run separately and is in itself an economically viable investment.

Figure 1 shows some of the typical subsystems of an integrated mechanical engineering system. They range from computer-aided design of the product, including its component parts,

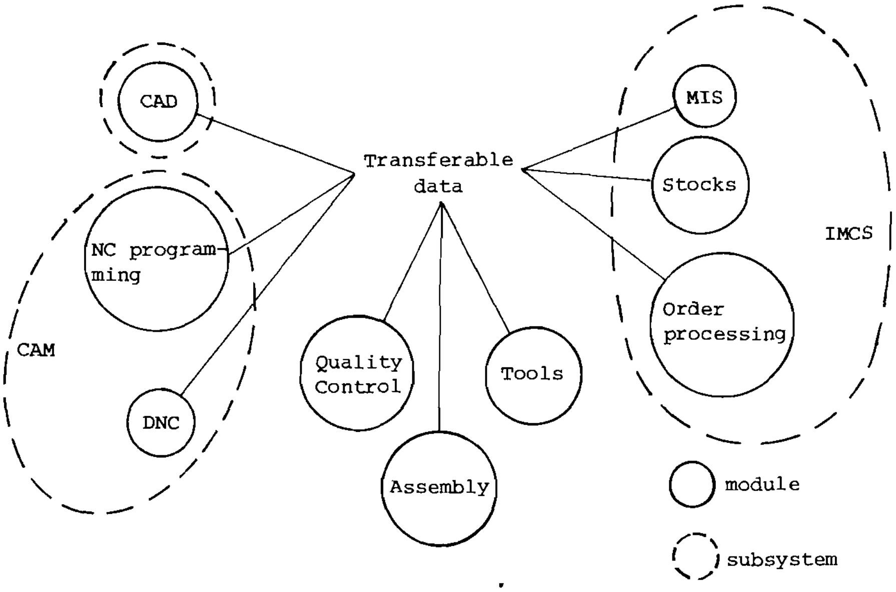


Figure 1. Some typical modules and autonomous subsystems of an integrated manufacturing system.

manufacturing technology, and the tools and fixtures needed to implement it, through the management information system, stock management, order processing, and other components of an integrated management control system, right down to the direct numerical control of the machine tools and the preparation of their control programs, that is, the shop-level integration known as computer-assisted manufacture (CAM). In the older diagrams of this kind, the subsystems were linked to a central circle labeled "central computer" or more recently "Factory Database". In Figure 1 we have--on the basis of the experiences hitherto gained--been more modest, and probably more realistic. The minimum needed for the integration of the subsystems is not some gigantic, structured database of millions of cross-linked items, but "only" the ability to transfer easily mutually intelligible data from one subsystem to another.

A brief consideration of the philosophy of the autonomous subsystem approach shows that it is, in fact, well covered by the first principle of the multilevel hierarchical approach, for here there is decomposition into a number of coupled subsystems. Let us proceed to examine whether the other two basic concepts also fit.

THE TIME HIERARCHY

Figure 1 is not akin to the usual representations of hierarchical systems, which are generally tree-like diagrams, and it suggests a clustering of many equipotent subsystems not subordinated to one another. This, however, is misleading, and the key to the true essence of this structure is provided by Lefkowitz's formulation of the second principle of the hierarchical approach, where he states that the subproblems must be "distinguished with respect to time scale".

Table 1. The time hierarchy (some typical data).

	Time horizon	Update
Design		
- of product - of technology	years	3 months
Order processing		
- end product schedule	1 year	3 months
Production scheduling		
- parts - tools - assembly	3 months	1 month
Workshop scheduling	10 days	daily
On-line schedule optimization	8 hours	minutes
Technological optimization	minutes	10 milisecs

Table 1 sets out the time horizons and updating cycles of just a few of the more important scheduling activities involved in various subsystems of an integrated manufacturing system. Even this very perfunctory sample shows that while there may be no immediately apparent structural or functional hierarchy, there nevertheless is a clearly visible time hierarchy, showing that the second enunciated principle of the multilevel hierarchical approach is also applicable.

SIMPLIFIED AND AGGREGATED MODELS

The most difficult--and hitherto unsolved--problem with respect to the synthesis of integrated manufacturing systems in the mechanical engineering industry has been that of designing subsystems that will interface efficiently with one another. The reason why this has proved such a formidable task has been that the modeling tools for examining the data transfer between subsystems and the dynamic interaction between the time-hierarchy levels have been totally inadequate.

That the problems of subsystem integration and dynamic stability can only be solved through the study of computer-based models is now theoretically acknowledged in a growing number of places, but the means for practical implementation are lacking. The real subsystems which are in everyday use in industry are immensely complicated and it is very difficult to discover the points where they can--as the multilevel hierarchical approach rightly wishes us to do--be "simplified" in such a manner as not to lose their relevance to the real-life situation. It is only when this has been done that it will be possible to "aggregate" them and use them for the synthesis of complex systems.

PROBLEM AREAS

The problem areas then, which require the application of the hierarchical multilevel concept to the integrated control systems in machine building, are primarily those of

- data transfer between subsystems,
- dynamic interaction between hierarchy levels.

If the concepts developed at IIASA in the course of the recent study of the steel industry can be used to further the solution of these two problem areas, a major step will have been taken towards the development of a universally applicable methodology for the integration of extant subsystems into fully integrated manufacturing systems. (At present, all the attempts at linking these subsystems are unique, pragmatic, and marginally efficient exercises.)

The first step should be the development of a good, computer-based structural definition and analysis system. While theoretically many such systems for describing structurally linked modules are available, the problem at hand poses very severe requirements with respect to the size, the complexity, and the heterogeneity of the modules to be handled, leading in practical attempts to quite considerable computational difficulties. To overcome these, it will be necessary first to implement an internationally transferable, conversationally oriented module-description procedure, which could usefully be offered through the planned IIASA computer network. This would greatly facilitate the entry of module descriptions by the numerous organizations in many countries that have expressed an interest in the subject.

Discussion

Long

In describing parts manufacturing you used many of the same words used yesterday in the discussion of the steel industry, planning, scheduling, etc. Why do you think, or maybe do not think, these problems are any different from those in the steel industry?

Hatvany

I think they are both different and the same. The fact that they are the same is shown by the use of the same words. The fact that they are different is mainly a question of scale, size, and complexity. And by size I do not mean here the weight of the material handled; I mean the number of processes through which the material goes and the number of variants and variables which have to be considered. So if you are considering just parts manufacture, not whole machines, you just consider this medium size factory with 105,000 parts, each part having 5, 10, 15 distinct machining operations performed on it, and you are already into the millions. And this quantative difference does mean certain qualitative differences in the ability to handle the thing and to keep it in hand, in control. That is the first and main difference.

The second difference is perhaps not so great, because you do get it in steel; that is you do get very different processes. I mean, you get smelting, milling, etc., but there is a fairly limited technological range of products. In mechanical engineering, the range is very much greater and the degree of freedom to manipulate the order in which these processes are performed is also very much greater. You do not have a fixed routine through which you have to go from the ore to the finished product, but with something like a block of metal you can choose all sorts of ways of machining and all sorts of sequences. So again you have a complexity problem which is multiplied, as it has to be, by the previous problem, but the number of things and the number of operations lead to almost unmanageable figures.

Lefkowitz

One of the objectives of your presentation was to say a little bit about what you had proposed for next year's research program in this area. Could you say something more on this?

Hatvany

I did not know whether I had the liberty to speak about something on which IIASA had not yet made a decision. So I have referred to these as "problem areas". I could also call them "research proposals" and I hope that we shall soon be able to call them, or some of them at least, a "research plan" at IIASA. So I would propose this first problem in particular, for IIASA; the integration techniques of modules into integrated systems is the thing with which we should be dealing primarily. In order to do this, first one must find a good structural definition of the analysis system and in this, I think, the work that is done so far can give us many valuable lessons.

For those of you who are perhaps not familiar with this we have been conducting a very very small scale effort in mechanical engineering systems at IIASA and this has been concentrated on computer-aided design. Last year we produced a world survey of computer-aided design activity; we prepared a report and had a conference on it, and we have also had some workshop meetings here at IIASA, especially in conjunction with the Working Group 5.3 of IFIP, the International Federation of Information Processing. This working group twice has considered close cooperation with IIASA in continuing research, partly in this area and partly in the whole area of integration techniques. Now the last meeting which was held here in Laxenburg generated great support for doing this. It was felt that it would be a good idea to use the techniques already partly developed and partly available in methodology--for example, from the methodology project and the large organizations project of IIASA--and that we could also work through the interaction of the other institutes within the member countries of IIASA and IFIP who try to do something concerning integration techniques. We have to get some kind of international agreement on definitions.

Williams

You are involved of course in all of these things around the world, Working Group 5.3, COPAN, CAM-I and many others. Would it be possible to take a few minutes to tell these people where some of those other projects are?

Hatvany

Well, I do not know how much of this is of general interest, but let me tell you that there is a large number of organizations. Now that we are beginning to throw their names around, let me write them down. Right at the top of the list if of course IIASA. Next is IFIP. Now in IFIP there is a Technical Committee 5 which is concerned with the industrial application of computers and the chairman is Mr. Williams. It has a number of subcommittees of which 5.2 is concerned with CAD, computer-aided design, and 5.3 is concerned with integrated manufacturing systems.

Now, there are various organizations that are dealing with numerical control programming languages. There is a triannual conference for PROLAMAT which is partly organized by these working groups and partly by IFAC, the International Federation for Automatic Control which is a co-sponsor. This is held every three years and the next one is in 1976, you are all very welcome to come to Scotland, Stirling University, in June 1976. Then there are various organizations concerned with programming languages for numerical control.

The main international organization is the International Standards Organization and, please forgive me if I do not have the exact number of the subcommittee, but I think it is 97/3/2, and it is for numerical control programming languages.

The main numerical control programming language that has been more or less accepted as an international standard is called APT, Automatically Programmed Tool. This originated at MIT in the US and now has become accepted worldwide. APT has been further developed by the Illinois Institute for Technology Research Institute, IITRI, and now additional development is being carried out by Computer Aided Manufacturing International, CAM-I, an organization based in Texas. This is a very active organization whose manager was here in Laxenburg quite recently. We had some interesting talks on the possibilities of cooperation with IIASA. Actually, CAM-I is involved in the whole business of integrated manufacturing systems, ranging from computer-aided design, scheduling, data management, etc.

There are other people concerned with APT languages in Europe, and there is a number of organizations. In the Federal Republic of Germany there is EXAPT and in France there is IFAPT (which is run by an organization called ADFPA). Then all these and some others are united in a committee which is our joint UNCL, which is the Unified Numerical Control Languages Committee. In the socialist countries, the Council for Mutual Economic Assistance has a unified language. It is a modular language, which is dedicated to become ISO compatible. So this modular language will also resemble the APT language because APT is the ISO standard. There are several numerical control languages that are being used at present.

That is as far as numerical control is concerned. Now for computer-aided design, here again there are a lot of organizations. Except for ISO, all these are national organizations or else voluntary organizations like IFIP, and they have no central staff, no focus point, no neutral common office to get things together, to organize and distribute them, and to get people together. And that explains why the initiative of IIASA to bring these people together and to act as a focal point for this activity was very much welcomed.

Williams

I got the impression, the way you described it, this was to be a proposal for research. It seems to me, and I beg you to clarify, you said rather that what is really needed is a proposal for organization.

Hatvany

Yes, I would agree with that, but would not separate the two all that much. What I have proposed in IIASA is a research program that would, in effect, be so limited in staff that the only thing it can really do is organize the efforts of other groups and organizations. This is consistent with the "decentralized" mode of activity for IIASA.

Integrated Systems Control in the Chemical and Energy Industries

J. Valdenberg

One of the questions that was put before the conference by the leaders is as follows: Is it expedient to extend the investigations of systems integration from the steel industry to other industries? I would like to explain some concepts of constructing integrated control systems for continuous processes. I will limit myself to examples from the chemical and energy industries; my institute has experience in designing systems suitable for both of these industries.

But, first, let me speak about my institute for a moment. It is located in Moscow and is called the Central Research Institute of Complex Automation (CNIIKA) which is part of the Ministry of Instrumentation and Automation.

We have already designed control systems for the energy industry specifically, the various technological units of power stations, using different kinds of fuels, with capacities of 300, 500, 800 megawatts (for example, nuclear power plants with boiling water reactors and with high speed neutron reactors).

In the chemical industry, we have considered ammonia production, sulphuric acid production, and the production of polyethylene. We are constructing control systems for these production processes simultaneous with the designing of the technological objects, and our experience was this: before we could consider the application of current technology, more powerful units had to be designed, which required some changes in the tasks of control. The improvement of these systems stimulates us to solve the problems of integration, and to pay more attention to problems of systems unification and systems flexibility. In other words, these systems should reflect the changes that are taking place in the technological objects, and they should be interrelated with other very close objects of control. Thus I would like to stress that we try to solve the problems of constructing the integrated system of operational control not by isolating one problem from others, but by taking them into account together.

The questions of the integration of these systems relate to specific features in the steel industry. I will give you an example. In one of the chemical complexes there are two ammonia production plants whose systems were designed by our institute. In the old plant, the sequence of five or six production units is separated by storage capacities for the semiproducts. Each unit has approximately 10 different divisions and the control system solves the problems for these plants and, in particular, for the financial interactions of the different processing units. In the new ammonia production plant, the total capacity is approximately equal to the old one, and there is in fact one very large technological aggregate without intermediate storage capacities for the semiproducts, without parallel technological aggregates. The task of operational control here has quite different intervals of control from those of the old plant, and just now we are observing the merging of different levels of control within that integrated control system according to operational control.

Simultaneously with these, we can note a kind of isolation of the functions of administration and economic control of the plant from this system of operational control in real time. Thus, according to the functional structure, we can see the merging of related levels of the hierarchy according to the tasks of operational control and some special features in the organizational and budgetary system. But an information connection between these two parts should exist.

The technical structure of similar integrational systems reflects the tendencies of the functional structure on the one hand. On the other hand, the providing of information concerning the process is quite independent and may prove to be inexpedient. First, it is very expensive according to investments, and, secondly, it is very complicated for the operational personnel, particularly in those cases where the information is put in to the system manually. Thirdly, it can lead to the distortion of information.

This is a general picture of the tendencies in constructing integrated control systems which we accept according to our experience. Therefore, to my earlier question, whether or not it is expedient to extend integrated control systems to other industries, and to what extent this should be done, I can answer that in principle it is expedient, and to our minds it is quite useful whether it is applied to one industry or to another.

On the one hand, we can consider methodological results to be more general and more constructive. On the other hand, the results that we have gotten in the steel industry can be transformed to be of use in other fields. It is obvious that to solve this problem it is necessary to set up the organizational network within IIASA. It seems to us that the thoughts that were expressed during the first day of the Conference about closer relationships with national member organizations will enable us to find the organizational ways that will allow IIASA to raise this problem more widely.

Discussion

Lefkowitz

Can you say anything about the relationship between CNIIKA as a research organization and industry with respect to questions such as who initiates research problems? how these are implemented? and what is the feedback relationship?

Valdenberg

Industry itself just initiates these problems, and in fact the very powerful plants that I mentioned cannot work without the control systems that we discussed. Therefore, we have no choice from the organizational point of view. Such works in our country are coordinated by our State Committee on Science and Technology.

Panel Discussion

Cheliustkin

To start our discussion I have asked some people to begin and carry on in three main directions. One direction is connected with scheduling problems, the second with individual control systems design, and the third with the generalization and conclusions. I would like to ask M. Knotek to begin this discussion.

Knotek

I am very happy to participate here and I think that there are a number of basic problems that everybody wants to solve with international cooperation. The first of these problems is that of identification of the controlled object. The problem has been discussed here many times. I think that this problem is a very old one, but theory unfortunately does not cover identification methods for planning, scheduling, and production control.

The second problem is the problem of structures: how to build efficient (hierarchical) structures, how to build control structures, technical structures, information structures, and organization structures, and how to provide a synthesis of these structures especially for the scheduling and control of production. Everybody uses his own methods. It would be very useful to develop some feasible solution for the beginning, and then find some more sophisticated methods for the solution of the structure problem.

The third area is that of scheduling and production control models. I think that, up to the present time, most of the systems that have been developed are information systems for scheduling and production control, and not for decision making. I think that many restrictions exist and that it would be very useful to deal with these restrictions and to show how to build mathematical models which could be used by companies in the development of their scheduling and production control systems.

The structure problem was mentioned in J. Hatvany's report this morning. He stressed four problems. They are, as I understand them, programming, tools, scheduling, and production control. Up to now we have used the common programming tools, which have to be used for data processing purposes. I think we need to consider some specific programming tools. These would be useful in the design and implementation of scheduling and production control systems, namely, in operational control systems. We need to have at our disposal some special languages, and maybe some special computer processors would provide the possibility of man-machine communications. I think that the suggested problems could provide a sound basis for future international cooperation with other projects and groups in IIASA.

Cheliustkin

Who would like to make some comments on this topic? It seems to me that for the operational control system, a very important problem is the motivation of time horizon.

Kopetz

Well, I think the problem of implementation, of getting the systems to do what we think they should do, is a very important one and also a very difficult one, maybe even one of the more difficult ones to take. I think that technologic and economic constraints somehow force another kind of structure discipline on the way we are supposed to do the job in the future.

If you look back to about five or six years ago, the idea was that we had to do everything with one machine. Now technology has advanced and given us the micro-computer. Mr. Williams told us that the new structure is completely different. The reason for the completely different structure, in my opinion, is that it has definitely been influenced by the technological changes. I am sure that within the next few years several further changes will occur in other areas of information processing. For example, in data communication and data transfer, I do think technological developments will also force some kind of structure on the system.

Long

I would like to suggest two other specific areas for future research. One of them is in the areas of forecasting. The presentation in the second section, of your State-of-the-Art Review indicates a definite need for medium-term forecasting because it is these forecasts that form the basis for planning. In our experience, the existing techniques are not satisfactory for forecasting sales (three to six months into the future) for purposes of planning.

Another area I would suggest that requires more research, if the general outline for overall control presented in the second section is to be fully useful, is the area of simulation methods. Fast-time prediction requires simulation models, models that can be used in an almost on-line way. Techniques do not exist today for generating fast-running, efficient models for use in an on-line production control system.

Lefkowitz

Mr. Long's suggestion of forecasting as an area of needed research implies that with enough study better forecasting methods might be forthcoming that would result in a significant improvement of the planning process. But there is always the question of whether there are some inherent limitations, say with respect to the information available, so that, even with a substantial effort, only a marginal improvement in the desired end result can be expected. I wonder if Long has any thoughts on this from the viewpoint of a user in industry?

Long

I think that there is sufficient potential for improvement and I think that it is possible to develop better methods for medium-term forecasting, methods that do not rely either entirely on time series techniques or entirely on econometric methods. It is my opinion that, were there effective medium-term forecasting techniques developed, they would positively impact production scheduling and planning. It would be possible to do a much better job of production scheduling.

Cheliustkin

May I ask a question concerning forecasting? Is your company creating its own forecasting models or is there some outside organization doing it?

Long

For long-term forecasts based on economic considerations, our company employs the services of the Wharton School of Business, University of Pennsylvania. For medium- and short-term forecasting, we make our own forecasts using techniques that we have developed ourselves or purchased from others.

Cheliustkin

What are the time horizons?

Long

Short term is one to six months; medium term is six months to two years; and long term is one to five years.

Cheliustkin

You mentioned an interest in developing more precise forecasting methods. Are you considering long-term or short-term forecasting?

Long

I think that both the long-term and the extremely short-term forecasting techniques are adequate for our purposes as we know them now. It is the range in between, from six months to one year, perhaps as short as three months, where the difficulty is the greatest.

Cheliustkin

Do these time horizons of three or six months have some motivation?

Long

The reason for requiring forecasts for three, six or nine months into the future is to make plans and decisions regarding semi-finished material requirements, levels of operation of the various facilities, manpower scheduling, and other such decisions.

Cheliustkin

And how about longer-term forecasts? How are they connected with investment planning?

Long

Forecasts one to two years into the future are too short term for investment planning. These would be used for decisions much as the ones presented in your second section having to do with raw material contracts, longer-term maintenance decisions, and decisions regarding long-term use of existing facilities.

Kelley

Can I come in on this one? It worries me, to some extent, when we talk about forecasting. Naturally if one could accurately predict the future, we would not all be sitting around this table here. We would be living in luxury somewhere. This is not the way life goes.

I am not sure what people mean by a good forecast. Is a good forecast, in effect, something that turns out like real life? Or is it some form of mathematical excellence, that everybody that looks at it says, "Yes, that's a good sound piece of analysis" and the result is okay. I do not expect answers to these points, but I am introducing a thought here; it is that maybe we should pay less attention to the accuracy of forecasts, because in many cases people do as well as they can. We should pay more attention to coping with uncertainty, because this is what it boils down to in the final analysis.

I will give you a very short-term example of what I mean. When you draw sections, H-beams, or I-beams, or whatever you like to call them, they often come in lengths of 300 or 400 feet, and they must be cut up into the lengths customers have ordered. There is a nice problem trying to decide which combination of ordered lengths you take from the next rolled section. I spent a lot of time in my youth trying to predict the length of that rolled section, and I gave up because there were so many uncertainties and a slight inaccuracy in weighing something, or a bit of slip on the rolls, and you add quite a few feet. So that was tackled from the other direction, which was to wait until you had an actual section you could measure, and then, while using a computer, you could select rapidly from a list of ordered lengths a suitable combination for this piece. That worked like a charm. I think you will find that this philosophy is used in many rolling situations at the moment. Now, this is a very simple example and perhaps a trivial one, but it does show me that we should concentrate on how to get out of trouble, rather than trying to avoid trouble, which we know in fact is a futile exercise.

Long

I would endorse what you say. Disturbances do occur. Predictions, by definition, are always wrong. There is a 50% probability that one will be high with his forecast and a 50% probability that one will be low. However, some decisions must be made in advance and must, therefore, be made with incomplete information. It is to make these decisions better that one needs a forecast, some kind of forecast, even if it is entirely subjective. These kinds of decisions are made in advance. They are, of course, modified by feedback as the future actually unfolds. Thus we must look at a combination of the two, forecasts and modifications by feedback, as key elements of production control.

Boyadziev

I want to propose another topic for discussion. What must be done while developing an integrated system to assure its acceptance by the people working in the plant? I ask this because I think that this acceptance is very important for the good performance of the integrated system.

Margulies

I think that this is one point that is missing in this project. If you speak of integrated systems in industry, certainly man is part of the system. It is not a question of making the people working at the plant accept a given system, but I think it must be part of the developing and designing procedure to have feedback from these people, to have ways of cooperation, coordination, discussion with them, and to offer to the people in the plant, from the point of view of the expert, various solutions from which they might make a choice with the expert. I know this way might seem to be very high in the clouds, but I think that this is a real problem which should be included in the research project of IIASA and in similar projects that are being done in other countries.

Cheliustkin

What is the problem when a new plant is being built?

Margulies

The same applies to new plants. If you build a new plant and you have other plants, you are not designing a new system from scratch. You are taking experiences of other plants for the system and you should also take experiences from other plants for the people. As an example (to be presented at the IFAC Congress in Boston in August), in Sweden they are now planning a new steelworks that will go into production in 1980. They have started research in the present steelworks on the problem of job satisfaction for the workers. The whole system of the steel works, including job descriptions, working environment is now being designed with cooperation between technologists, control engineers, social scientists, and psychologists. The psychologists are basing their proposals on the results of more than 1,000 interviews they have made in existing steel plants.

Cheliustkin

Are you considering only workers or the managers too? When the new planning and scheduling system is installed, the previous tasks of the manager are no longer necessary and he should be replaced.

Margulies

I do not mind if the manager is satisfied too. You have people working with the system and no matter where they stand in the hierarchy you have to find a solution, a solution that fits the necessities of the work, the plant, and of the workers themselves. This is done to make sure that the worker will not have an accident and also to provide him with a job in which he is given a chance for creativity. Certainly not everybody is willing to have a creative job, but those who want it should be given the chance.

Rolle

This points to the question, "Who should be responsible for creative solutions in such areas?". My feeling is that only the plant people could be really responsible. If someone from the outside, for example a consultant firm or a supplier, is responsible for the project, I have the feeling that the possibility for failure is very high, because outside people do not know the process. They have to work with the whole thing if it is to be implemented successfully.

Cheliustkin

It seems to me that there is a general approach to management and control problems. This approach is based on different time horizons for the problem solution, and it does not depend on whether outside people or people from the enterprise are responsible for the system design.

Wolfbauer

I would expect some success if you structure the problem by distinguishing the problems of estimating, forecasting, and risk assessment from the mathematical tools to handle the information. Doing this, you will see that tools are already available, for example stochastic simulation. Regarding estimation, it is not necessary to come up with a unique, determined figure, though of course it would be a very good solution. But when management makes a forecast of several types of distributions of definite products which would be the program for various time horizons, then you can take the simulation model, make experiments, and come out with a solution for the design of capacity. If there are no deviations from this forecast, you will have a single design; otherwise you will decide for a flexible design to react to market changes.

Cheliustkin

But at the beginning you have to estimate the demand, and this can be done only within some probability. Over the long-term planning horizon, you do not know what kind of strip you have to produce; you only have the forecast figure of so many total tons of strip that you have to produce, without indication whether it is thick or thin strip. So, for the long-term plan, you have to use very average figures. When you already have a set of orders to be manufactured, you know what thicknesses, widths, and steel grades are to be produced. So for the short-term horizon you build a more realistic and detailed model.

Wolfbauer

Yes, you hit the problem exactly, but I would cite a market study I was recently involved in concerning demand for special pipes. The description was very exact, but the main problem concerned how to translate the results of the market studies to pipe specifications. The sales and production people worked together to make some alternative production programs, and we ran a model to see how the capacity should be designed. You do not come around to that decision for the program. If the demand is very uncertain, you attack the problem by building up a very flexible design.

Cheliustkin

If the demand is equal to the capacity of the mill, the problem is very complicated. It is much simpler if you have excessive capacity. My idea is to use the risk function, which should be considered when you are estimating for planning. Standards of process performances should be different for the different time horizons.

Wolfbauer

You are right, but there is quite another problem. The management does not know their own risk functions. They have very subjective risk functions. What should they do with the risk standard of a processing type? You see it is a problem of looking forward and if you see it is a very uncertain situation, you must make a very flexible design. It is the same as Kelley said. I do not think it is a problem of computerization. We have risk models that were developed 200 years ago for experiments repeated very often. But investments do not often get the use which is promised by probability.

Kovacs

I would like to comment on this stochastic problem. It is also possible to consider long-term planning in another way. If we had a kind of distribution function for our demand, then we do not have a good forecast; we could determine a best solution based on expected values.

There is another point I want to make. In long-term planning, uncertainty is quite great. As we get closer to current production, the uncertainty becomes smaller and smaller; however, when we get to the actual production, it sometimes gets bigger. For example in steel production, it is not possible to produce exactly the same quality of steel every time. For this reason, some kind of stochastic approach is needed. Thus, if the grade of steel obtained does not satisfy the order, it is possible to plan for its use on a different order. So, what I wanted to say is that the stochastic approach to these problems might be very useful in carrying out the planning function.

Cheliustkin

I am not sure that it would not be more difficult to find and establish a distribution law or to determine what the risk function should be. So, maybe the problem is the same.

Kovacs

Well, I can give other examples of this stochastic approach, which has been applied by our institute in an on-line working system. The reliability of the system, in this case, was very important and a stochastic programming model was developed and the model was identified at exactly the same cost as would have been incurred by using another solution; however, the reliability of the solution was increased from 10% to 90%. That is not final; they are still continuing this research. But this kind of thing can be done.

Long

I would like to offer a brief comment. In our experience we have found that a stochastic representation is very useful in longer term planning. Our experience is also that, for short-term scheduling and production control, it may be possible to mathematically characterize disturbances, but the characterization is computationally unattractive. For production control, we choose to proceed on a deterministic basis, but we use feedback to make any necessary adjustments as random disturbances are detected.

Kelley

May I offer another example of the stochastic approach? It is my understanding that, at a steelworks in The Netherlands, the melting shops were told to attempt to make only six different types of steel. These were carefully chosen across the spectrum of the analyses required. The frequency with which they attempted to make each of these six was adjusted month by month depending on the order book. What happened in practice was, like all good steel makers, they did not always make the steel they attempted to make and this gave them the spread of analyses they actually required.

Kovacs

I would like to make a point on the application of computer simulation for a short-term solution. In cases when you have a change in your simulation for example, changes in quality or dimensions, you can test rules of priority for scheduling as we did for a plate mill.

Cheliustkin

In some of the highly automated works of Japan there are no alternative schedules. The people from these works say that their system is so good that changes are very seldom required.

Kovacs

With stochastic problems, I agree that stochastic methods can be applied, but in many cases, more sophisticated methods of stochastic programming can be much more efficient, although they may not be right in all cases.

Cheliustkin

I agree that stochastic methods cannot be used for short-term scheduling. But the use of the risk function to estimate the productivity of equipment for a short-term horizon has some advantages. For instance, to schedule a rolling mill you have to know the cycle of the operation and variations of this cycle can result in postponed operations. So you must have some built in tolerances, just to be sure that there will be no time contradictions.

Kovacs

Well, I agree that in the case of scheduling the stochastic program may not be very good, but I would not be afraid of considering it either.

Cheliustkin

So, it seems to me that for long-term planning and for some medium-term planning as well as some of the long-term scheduling, this method should probably be used because it gives more consideration to reality.

Lefkowitz

We have been talking, for the most part, about what should be done in the future and in what directions we should look. But one of the objectives of this panel discussion is to consider the preliminary State-of-the-Art Review that has been prepared and to get some feedback with respect to omissions, the emphasis given to various topics, or examples in real life that you people are aware of that are not adequately reflected in the report. Are there any contributions in this vein?

Williams

In the light of the subject I. Lefkowitz has brought up, I would like to comment. The Integrated Industrial Systems Project at IIASA is comprised of a group of exceptionally qualified individuals from a wide variety of backgrounds and experiences who have had collectively the unparalled opportunity of reviewing the state of the art of iron and steel production at 35 organizations in 11 countries around the world.

The results of this study could thus have been an excellent opportunity for the establishment of a "snapshot" of the state of the art of the development of integrated industrial systems throughout the world at this point in time. It could also have produced a critical evaluation of what is practical and what is possible from among the many proposals that exist today for potential future developments in this field. Neither of these would have to identify the companies or the countries involved.

Unfortunately in their Preliminary Draft Report, the IIS Group has chosen not to attempt this very important analysis that could be done only by their group. The review that we have seen and that has been described to us by the team members relates in an excellent fashion the kinds of future activities that might be undertaken by the various iron and steel companies around the world. What all of us need, but is not supplied in the Preliminary Draft Report, is a statement of how much of this has already been accomplished successfully by one or the other of the installations visited and what might be the probability of success in developing those things not yet accomplished. An additional important factor here would be an estimate of time scale under which these reviewers feel that these developments will be accomplished with present research schedules and particularly <u>how</u> these time periods might be shortened. Further, their suggestions of specific joint researches that might be carried out by the IIS Group and their cooperating partners to further these aims would be very helpful to us.

The kinds of analyses and comments requested here, we feel, are especially important in terms of the topics in the theory of multilevel and multilayer systems. What aspects of the theory as described in the report have already been applied by the iron and steel industry? What other aspects could be readily applied and how might this best be accomplished? How would the team members recommend that research be carried out on the remaining aspects of the theory so that they might be developed and applied in the future?

A very interesting point for many of us would be an analysis of just how theory versus ad hoc practice was used in the development of the newest systems that the team members reviewed on their trips.

Kelley

Concerning the question of what things described in the review have actually been applied, I accept the criticism that the distinction is unclear, but in practice there is very little in that review that has not been done somewhere.

Lefkowitz

From the standpoint of the objectives of the survey, is it not sufficient to identify that certain things have been done successfully somewhere without necessarily indicating the extent to which they have been applied throughout the world?

Williams

Well, obviously the extent would be very helpful. You may not have had the chance to see enough to know that. We all know that the second people to do something do it much faster than the first ones did it. So, for somebody to know that it really has been accomplished the first time is very important.

Cheliustkin

Even if you know the extent, what do we do in the case where, as in some of the systems described, one part has been implemented in one place and the other part in another place?

Williams

I realize that you cannot say that this has been done in a particular way, because of proprietary restrictions or because you do not like to make comparisons. That is fine. But I think it is very important, for example, to say if something has been accomplished, because only you in the world have had the opportunity to get this information.

Kovacs

I think it would be very useful to point out the differences in the problems of different models because I am sure that the model for a new highly automated steelworks with many large computers has problems that are sometimes completely different. Just as steelworks are different from other kinds of factories, so even some of the basic problems are different.

Kelley

I think you are following a point that was made on a previous day: that is, if you have a tired old plant, you do not put sophisticated control systems on it. You apply a lifesaving kit. But, if you have a really nice, modern plant, then it is worthwhile to put sophisticated control systems on it.

Cheliustkin

I was just thinking about the operational controls for a rolling mill which I mentioned yesterday. I described a system that was developed maybe 10 to 15 years ago without using a computer, but the performance of the process is very good. In my opinion, it is an advanced system, although it has no computer. So, I am note sure whether it is necessary to emphasize the novelty.

Williams

Well, I am not particularly hesitant that a comparison be made between new and old. What I think is important is that new techniques be brought to our attention in terms of what has been done.

Cheliustkin

But, the functions are exactly the same.

Williams

There is nothing really magic about computers. If you can do it some other way, that is also fine. That should be mentioned also.

Kovacs

I would also be interested in getting information about the effort that has been spent in the development of these systems.

Kelley

My experience has been that in making visits the nature of the information obtained and its quality differ from place to place depending on the particular circumstances: with whom you are talking and so on.

Lefkowitz

My attitude is that we are aware of many shortcomings in the Review and that is the reason why we have labeled it a Preliminary Review and have limited its circulation just to the people here at this Conference and those who helped us on the survey. Of course, we would prefer that it was already a polished document, but it is not to our advantage for you to describe it other than the way you see it. From our point of view we want to produce the best document we can within the time constraints, hence our desire for effective feedback at this stage.

Williams

We would hope that you appreciate the criticism of the document and take it as a suggestion of the kind of approach that many of us wish you had taken.

Long

A significant point was made earlier regarding how the Review can be enhanced. It is not clear from the descriptions of several of the functions, in the second section for example, whether the functions are being performed well or poorly, manually or automatically or how. I think that you can add much to our reading of the Review by telling whether the functions you describe are being accomplished elegantly or arbitrarily.

Rolle

You have been studying the production planning and the operation of control systems. You have found that the multilevel hierarchy offers the best solution in that area. Now my question is to what extent could this approach be extended to head office functions like invoicing, accounting, shipping, order-processing. Have you already found a way in which this head office function is done by multilevel hierarchical systems?

Lefkowitz

I do not normally place the functions of invoicing, accounting, etc., in the category of decision making and control. Rather, I think of them (in the context of the multilayer hierarchy) as part of the implementation stage of whatever decisions, control actions, etc., are to be carried out. They are in the category of routine operations that form part of the "overhead" necessary to keep the system going in a feasible and acceptable mode.

Rolle

Yes, but you could also install a specific system that just includes the routine operations in invoicing or shipping or order processing or whatever. What I want to say is that we can always reorganize work that normally is done on one big machine. There is a strong relationship between someone who has already ordered something and someone who wants to know if it has been shipped or if it is in production.

Kelley

Regarding these invoicing and payroll type exercises, I have never thought of them in terms of hierarchy, except that most people have levels of hierarchy and frequently you hear that the top one is an off-line batch mode, which is the garbage bag of everything that will not fit elsewhere. The rest of the theory gets put into that, and so in that respect I think there are companies that have this zero level, which is not on-line with feedback. The order entry, though, has a significant place in the hierarchical system.

To my mind there are two main flows of thinking. One is the planning line, starting with the long term, thinking of plant facilities and so on; the other relates to scheduling and plant operating. Eventually you get reality coming in with specific orders and the flows merge at, roughly, the month to three month level, after which you are into real-time operations. We also found companies who used their highest level machine to carry out some of the real-time work associated with order entry and also some of the batch work, like payroll, within the same machine.

Kovacs

I understand that the available theory is much less than what is necessary to develop the models and so on. I think it could be extremely useful, to at least be able to identify which problems are solved by only data transfer, which by some kind of heuristic methods, and which by other ways. I really do not know whether this is possible, because it is a big job, and I do not know how much information is available to you.

Cheliustkin

Surely, this is very useful information, but we do not have such information on full scale. In some cases we know, for instance, that heuristic algorithms have been used and these algorithms are being improved all the time. In one Japanese steel works, for example, there are more than 100 people working on the improvement of algorithms and software. We have not found examples of mathematical methods applied to planning and scheduling except for the problem of resources allocation. In all other cases, decisions are made by men, while the information for the decision is prepared by the computer.

Mazel

For us as an international institute to determine all the theories and techniques used in production control, planning, and scheduling, and include also all the simulation methods that are used is impossible, because you really cannot get all the information. One problem is that some of the descriptions obtained are obsolete or very specific. The other problem is that many simulation techniques convey some information about the plant application that is considered secret or proprietary. That is the reason that the simulation techniques are often not revealed.

Findeisen

Some of the questions presented yesterday by A. Cheliustkin, appealed to me, and I will direct my remarks to them.
Mr. Sawaragi will continue with remarks concerning the fourth section of the Review and then Mr. de Gregorio will follow with further comments.

In the temporally multilayer hierarchy, we have of course a certain long horizon and simple model at the top and we must have a complete model at the bottom. We may have several intermediate horizons and intermediate models in between. Now, if it has to be a long horizon, the question is, how long? If it may be a simple model, the question is, how simple? The same relates to the intermediate horizons and the intermediate models: how many? how different? I understand that future research should provide a basis for making such choices and also show how to link the layers, what procedures to use for model adaptation, what models to use for on-line optimization, and so on. The sources for answers to these questions may be found in the sensitivity theory of optimal control, but there are very few such questions that can be answered in closed form or by explicit solutions. Therefore, we have to rely on case studies and, I am glad to say, we have to rely on common sense. The kind of questions we pose may not appeal to control mathematicians.

Now, let us make a few more remarks on the time horizon and simplicity of the model. A qualitative answer is that a time horizon should depend on environment prediction, that is, how fast are the changes in the environment, and how long do the future expectations of the environment depend on the present observation? Secondly, the time horizon should depend on system dynamics. It must be longer for a slow system and shorter for a fast system.

If you want to learn what will be lost if you shorten your time horizon, then you have to get some numerical values. We did this for a linear quadratic problem and found that the necessary time horizon was unexpectedly very short, provided you use the repetitive optimization principle. According to this principle, your time horizon might be, for example, one day, but you use the results of the computation only for say, the first two hours. The control computed for these first two hours is not affected very much by the fact that you were computing for a horizon of 24 hours rather than for seven days, for example. The results for the linear quadratic problem were also confirmed by a case study done on a gas pipe line optimization problem where the main horizon considered was seven days. We found that if we reduced this to only one day, the first two hours of control were almost unaffected and we decided that 24 hours were enough as a shifting or floating time horizon for this gas pipe line.

Now, let us go to the other question. How simple can the model be? The qualitative answer is quite simple. You do not need any detailed initial state to determine the very distant future. If you want to plan your steel production for a year ahead, you do not care how many billets or slabs you have now in stock. For a similar reason, Forrester was permitted to use only five state variables in his long-perspective world model. The quantitative answer to model simplification is missing. I do not know about a sufficient rational basis for aggregating these state variables, showing how it would affect your results. You should note, however, that the control action you have to take now requires specifications of all the details of your plant. You have to tell the crane operator which piece of iron to take from which pit and where to put it. That is the reason I said that at the bottom you must have a full model while at the top you may have a simple model.

Let me now make a few comments on multilevel structures of on-line control, starting with open-loop systems. What we need is model adaptation techniques. Open-loop systems are very nice because they are never unstable, but adaptation takes time and certainly there are some limits to applying adaptation. We may set up systems with feedback for steady-state optimization. What we need here are procedures of on-line coordination as opposed to mathematical problem solving, and procedures of on-line subcoordination. Subcoordination is a kind of suboptimal coordination. Since the number of coordination variables tends to be very high, you are inclined to consider only the principal part of them, for example to consider aggregated or group prices. The result will be suboptimal but meaningful practically and that is the reason subcoordination, in my view, should be intensively explored.

Another topic is how to ensure that the on-line controls do not violate the real system constraints since we are calculating controls by using models. The real system will differ from the model and hence the system constraints may be violated. Some safeguards have to be built into the algorithms or into the instrumentation.

A topic of recent interest is decentralized control of an interconnected system like private firms acting in a free market. Another topic relates to dynamic coordination of systems with feedback. In the open loop there is no difference, but dynamic optimization with feedback introduces new problems. We should explore the method of dynamic price coordination, and we must also look for other possible structures. One possibility is to use the primal coordination method for soft interactions.

There are certainly other general problems. In multilevel control theory, we would like to have tools to handle hybrid systems consisting of continuous and discontinuous operations. We would like to be able to consider the cost of information transmission, data processing and storage, etc. It makes a lot of sense to consider what is the cost of information transmission as compared with the improvement of the performance of the system. Another upcoming problem area is optimization with vector performance criteria. All of these can be grouped under the category "Theory of Control and Coordination in Multilevel Systems", and they are being currently developed in many places around the world.

Sawaragi

I would like to comment on the fourth section of the State-of-the-Art Review. This section is an excellent survey of the steel industry from the theoretical point of view. The multilevel hierarchical system theory has become very famous in systems science. However, in my opinion this theory seems to be much too philosophical, and there is still a great gap between theory and practice. The real existing system is generally very complex, and it is generally a very hard task to describe the character of the system identification problem, which is often more important than the optimization problem. I would like to ask I. Lefkowitz how your theory affects the practical procedure of systems analysis in the steel industry?

Lefkowitz

Let me respond first to Mr. Sawaragi. I agree that there is a substantial gap between theory and practice, not only in the steel industry, but in industry in general. My attitude, in regard to the conceptual formulation in the fourth section, is that the hierarchical structures that are described do exist. I would argue that the concepts and structures presented here are carried out in practice, but in an ad hoc way. What is missing, where the gap lies, is in the availability of effective analytical tools and quantitative methods by which large integrated systems can be designed on a systematic and rational basis.

I would also make another point and it is a semantic consideration. I use the term "optimization" for convenience, as a label, to mean essentially doing the best possible under the circumstances and limitations. In very few cases is optimization in a mathematical sense actually implied; more typically, perhaps "satisficing" is a better term.

With regard to W. Findeisen's comments. I agree with the points that he made in reference to the areas needing further research. I think I would underscore even more the need for more rational bases for the formulation of the models that go with each level and layer of the hierarchies, and for the determination of the appropriate degrees of aggregation. At the present time, these are in the category of unsolved problems. They are handled in everyday practice, but as a result of ad hoc procedures, norms and conventions that have evolved in practice, etc.

The same thing is true with respect to the choice of time horizons. For example, industries do operate with specified time horizons for different kinds of decision problems, and the choice of these horizons, it seems to me, is determined in part by historical evolution, in part by practical considerations. The temporal hierarchy of planning functions--annual, monthly, weekly, etc.--is clearly tied to the calendar because of the fact that it relates to the activities of people, their work periods, and other relevant factors.

One can make a strong argument, and I concur, that theory can give us better insight on how to choose the horizon, the frequency of updating, and other questions of this kind, so that we have a better overall result. Again, I think that the requisite theory is something that will evolve with time and effort.

My last comment is with regard to the matter of satisfying system constraints. There are two kinds of constraints we may consider here: those that are automatically enforced by the system such as the upper and lower limits on the flow through a valve, and those that must be imposed externally through the action of the controller. In the latter category would be the constraints on furnace wall temperature, or the temperature limits on strip exiting the hot strip mill. If the constraint is important, then it will be enforced explicitly wherever feasible, that is, through direct measurement and feedback action. Thus, if the model is incorrect or inadequate, it is not the constraint that will be violated but the computation of the optimality conditions.

Kovacs

I fully agree with I. Lefkowitz that there is a big gap between theory and practice, but there are an infinite number of possibilities in between. I have two points. First of all, if we mean by "analytical tool" a solution that can be given explicitly in a specific form, then we have to mention methodology and heuristic techniques (including common sense) which form a very big set. In other words, even though an algorithm may be supported by many theories, if it does not give a solution within a reasonable computation time, then it cannot be considered optimal. So it might be this heuristic algorithm that I am talking about that might be much more theoretical than another so-called theoretical algorithm. In general, I would not say that the heuristic solution is the opposite of a strong analytical solution; rather, it is the opposite of a guaranteed, exact optimal solution. In other words, the heuristic does not yield an exact optimal solution, but frequently it includes many suboptimal solutions, which is the same as optimizing a part of the problem. In some other cases, the solution is optimal in only a very limited sense. If this is so, then this heuristic approach which is applied in the steel industry might include a large variety of methods.

I have more comment on goals. It was said that there were no goals other than optimization. Well, let us consider the problem the following way. We have some kinds of constraints and some kinds of goals. If we can correlate these goals in a single objective function, then this produces an optimization problem. If there are several objective functions, then it is also possible to convey the result as an optimization problem. If you have another problem that is not considered an optimization problem, this may be so because it is too complicated to yield a solution. In this case, we need only a physical solution, but if we can get a better solution, in some sense, then it is right to get this kind of optimal solution.

de Gregorio

The scope of my few comments is to give a slight contribution on two broad aspects related to the theme covered in the fourth section of the State-of-the-Art Review prepared by Messrs. Lefkowitz, Cheliustkin and Kelley: 1) the need to arrive at realistic results, and 2) the need to reach such results devoting resources and time that can be reasonably faced even by companies that are not among the few largest in the world.

On this second point, I would like to recall what Cheliustkin said in one of the sessions. He emphasized that the effort cannot be transferred to vendor organizations outside the steel companies; you have to know in great detail all the various aspects of iron and steel making technology and the related organizational peculiarities. What I believe is that the total effort falling on steel companies can be split into two parts: one of a more general nature that is by and large constant, that is, independent of the size of the plant, and the other, more specific, that is addressed to the particular situation of the given enterprise and that is in some proportion to the capacity of the plant. I think that a most valuable contribution can be expected from IIASA in reducing the effort required for the first part, in other words to allow companies to enter this field successfully without being obliged to set up and maintain for years staffs of hundreds of people.

I will try, in my following remarks, to use as much as possible the basic classification given by I. Lefkowitz and to follow the terminology adopted by him.

PLANT

Model Simplification

Let us deal first with the simplification of models proceeding up the hierarchy, hopefully through systematic procedures. Some of the variables can be neglected just on the basis of input-output sensitivity analysis. Some have to be retained because they significantly affect the performance index; but also in this case much could be done through a sound aggregation of variables in order to arrive at a reasonable number, that is, to reduce the dimensionality of the problems covered by the different levels.

A good example, coming from a field very far from ours, is macroeconomics. In this discipline, the availability of aggregated indexes is an absolute necessity when you try to interpret very complex phenomena such as economic cycles or behavior of large segments of economic activity. But also in the technological world we have examples at the shop level of the need to use a few synthetic indexes or parameters, to try to characterize complex physical properties such as the grade of steel or the chemical reducibility of the raw materials.

As far as the dynamic behavior of a plant and its organization is concerned, we need to cover in the model only what is really significant at that particular level, characterized by a specific time horizon as mentioned many times by Cheliustkin. In other words, the fluctuations on a small time scale have to be covered and controlled on the lowest level of the hierarchy and can be neglected on the higher levels.

Model Techniques

Next, we can consider techniques for constructing models or input-output relationships describing the higher level behavior, starting from the lowest, most detailed level (the process or unit control level) at which a great many verified models are already available. I think that, although the structure of the model is quite different at the different levels in order to take care of the mixed (both discrete and continuous) nature of the state variables and to embed new concepts such as incidence and precedence, as mentioned by Mr. Williams in his contribution, it is possible in this development to apply usefully the normal classical methodological scheme.

Internal Identification

Internal identification means that the necessary logical and physical relations (such as material, energy balances and so on) are written down in order to represent the interconnections of the subsystems pertaining to a particular level. For the representation of such single subsystems the models already developed and proved at lower level are used. It is essential to have available an efficient methodology to simplify the overall structure. In some cases it is possible to produce general criteria to arrive at the best schematization in terms of conflicting requirements in quality of results and complexity of models. In other cases the only way may be to simulate the system, using the set of elementary relations mentioned above as a basis for reproducing the behavior of the overall system, and from the responses obtained, try to synthesize something reasonably simple: this last procedure is conceptually very similar to the following method.

External Identification

Exernal identification means duly interpreting the response of the system under investigation or physically similar systems, and parametrically adapting this response to the response of a class of canonical structures. I do not know whether at higher levels it may be possible to find out interesting regularities as is the case at the lower levels. For example, much could be done in process control just by supposing one or two dominant time constants and a pure delay. Such a monster as a blast furnace (hundreds of equations at the microscopic level) can be fairly well interpreted in this way.

Everyone will agree that the structure and the degree of detail of a model are heavily dependent on the scope and purpose of the model. Therefore, if strategies of an incremental type are adopted in planning and scheduling, as will be mentioned below, it is possible to envisage opportunities for drastic simplification of models (linearization and so on), helping us to arrive at a good level of standardization.

ENVIRONMENTAL DISTURBANCE

Here the information related to systematic trends and to the superimposed statistics is the most important element to be collected and evaluated in order to arrive at a general description. The magnitude of the disturbance will have much influence on the controller strategy and on the complexity of the related algorithms. For small disturbances, the existence of lateral linkages between members located on the same level can effectively contribute to avoid the need for any intervention from the higher level, as we will see soon after. For medium size disturbances, some very elementary coordinating strategy might be sufficient. Only for large size disturbances is there required a major optimization effort on the part of the higher level controllers.

PERFORMANCE EVALUATION

If the purpose of the control is the minimization of operating cost, my recommendation is to use realistic figures of merit, closely related to the economic requirements of the section of plant in which we are interested. Some conflict may arise here between the formulation of figures of merit dictated by a realistic economical evaluation of the operation, and other structures that serve only to facilitate the running of the optimization algorithms. I am worried about the fact that in many cases at the process level, using academic figures of merit, usually quadratic forms on the relevant variables, one has to look at the end results and eventually to adjust, by trial and error, the parameters of the artificial performance index in order to arrive at a satisfactory behavior of the controlled system. Incidentally, in a situation like this it would be impossible to introduce parameter modifications injected by variations of the environment variables, such as prices of raw materials or cost of energy, etc.

A similar recommendation will entail also the structure of technological constraints. In the State-of-the-Art Review the maximum rate of change of temperature in the final or soaking zone of a reheat furnace is explicitly mentioned among the constraints to be satisfied. I would add that it is also a constraint in the tonnage zone; unfortunately, this value is not directly measurable since it is related in a complicated way to the form of the flame, the type of fuel, the emissivity of the slab surface, past history, and so on. To be more realistic, the rate of change of temperature in the tonnage zone is, in effect, only an indirect constraint variable: the true constraint is the endurance of the material and this depends greatly on the grade of steel, its temperature, and related stress distributions.

CONTROLLER

There are a few points in this area I would like to mention.

Structure

The main elements of the structure will surely be dictated by historical developments and the nature of the equipment as already mentioned by I. Lefkowitz. Nevertheless, I think that some degrees of freedom are still left to the system designer. You remember the possibility, mentioned yesterday, of using lateral linkages between members located on the same level. Let me use the label, hybrid hierarchical system. I will explain this point by means of an example taken from human hierarchical systems.

If I need some help because interface problems prevent me from successfully carrying out my assignment, I can go to the coordinator for an indication where to find somebody able to give me the necessary information. But the most obvious solution is to ask my colleague in the next room for his help. If he has the time and if the load I impose on him is not unreasonable, very likely the problem will be solved neatly without bothering the upper level with matters that are not pertinent to its degree of competence. Too often the management system is so structured that the coordinator has to intervene repeatedly for various minor reasons. A well organized system will provide sufficient decoupling for the manager to think about strategic problems pertinent to his level and not burden him with a lot of futile minute-by-minute decisions that can be easily settled at the lower levels. This means motivating as much as possible the collaboration among the colleagues working on the same level on different but interconnected professional activities.

Coming back to our plant hierarchical structure, the characterization of a certain hierarchical level boils down to choosing between the criterion based on time horizon and the criterion based on the subsystems coordination task. Sometimes a conflict may arise between these two different requirements placed on positions located at higher levels.

It would surely be beneficial to leave some initiative and decision freedom in programming and scheduling at the lower levels in order to allow local compensation against a normal amount of disturbances, especially in the class of minor contingency occurrences requiring corrective actions on a small time scale. This initiative capability must also cover the possibility of asking directly for adjustments to the next unit allocated on the same level.

Just one example in the steel shaping area: a small disturbance in a reheat furnace can be easily compensated for by slowing down or speeding up the pacing of the mill without producing any major need for rescheduling. In other words, if it is possible inside of the time horizon of the low level systems to cope with a disturbance through mutual aid, it would be preferable to leave the task of compensation to the unit controllers even if this is likely to introduce some degree of interaction among the units and cause a momentary relaxation in the value of some constraint.

For a smooth running plant operation it seems to me that the following conditions have to be satisfied:

- The allocation of the unit that is to help can be easily identified.
- The foundation for an operative decision must be based on straightforward algorithms and a clearly defined segment of the whole information base describing the actual situation in the area covered by the coordinator.
- The structure of the hierarchical system must ensure a sufficient degree of stability; in other words, it must be capable of isolating the effects of disturbance, or minimizing its propagation. Here, it seems to me, there are at least two ways to get this behavior:

    1) by accepting some marginal degradation in the quality of results by introduction here and there in the planning and scheduling programs of margins in the production or in the efficiency levels and therefore alllowing for some losses (suboptimality). Some degree of loss is a general way of stabilizing systems. One good example is an electrical network. A second example is the economy: in the stone age the economy was very inefficient but very stable; in more modern times, multilateral arrangements in international payments were found to be not as stable as bilateral arrangements, and the complete convertibility of the different currencies has been giving a lot of trouble purely from the point of view of system stability.

2) by devising a structural design that avoids, as much as possible, instabilities owing to secondary interaction effects generated by inappropriate loops.

Another benefit that one can get from limiting requests for action from the upper level to only major disturbances is the capability of grouping many infimal controllers under a single coordinator. This would have a significant effect on the structure of the overall system. It has been a well known fact of organization theory (for some 70 years or so--I am referring here to the work done by H. Fayol, the French pioneer in management science) that the number of people in a company has a major effect on the number of levels, but also that this effect is not rigid and the spread of levels depend on the degree of information (access to data banks) and the amount of decision freedom available to the people involved. It may be nice to discover, in the theoretical development of hierarchical control systems, regularity patterns similar to those found in the military or other well defined organizations. For example, in any army, you find that, at the patrol level the fanning is quite high; at the higher ranks the fanning is much lower, say between three and five units under a single coordinator.

Experience

I have already mentioned incremental versus absolute strategies in planning and scheduling activity. What I advocate here is simply making use of as much past experience as possible. I will mention here the observation of Cheliustkin, commenting on a visit to an English company. After two years, 80% of the optimization at the operational control level was predetermined based on prior experience and frozen in the data bank. Perhaps through collateral work on off-line simulation models one can imagine speeding up such an accumulation process and thereby reducing the area of strictly new situations.

Systematically exploiting this fundamental grid of experience, it would surely be possible to reduce a great deal of the sophistication of optimization algorithms, because you already start from a situation that is likely very near the optimal one. In such circumstances, it is concurrently permissible to relax on the quality of the figure of merit, and this freedom could be used to modify the figure of merit so that the optimization procedure can be speeded up. In effect, I suspect that for most cases the optimal point is immediately determined by the constraints, without even considering the figure of merit.

Definition of Time Horizons

Another area that, in my opinion, deserves some attention is the evaluation of the most suitable time horizons and the related time intervals between readjustments of the responses to the incoming data from the plant and the environment. I wonder if the year, trimester, month, week, and day are really dictated by the optimization requirements or, instead, are more strictly correlated with the movements of the moon, the sun, and the stars in the sky. To my mind, we need here more diversification at the different levels for different functions following the criteria sketched by Lefkowitz in his report.

Lefkowitz

I would like to thank Mr. de Gregorio for his very perceptive and detailed commentary concerning the conceptual and analytical aspects of hierarchical structuring and integrated control of industrial systems. I am in substantial agreement with the points he makes, most of which complement or reinforce those presented in our Review. His remarks include a number of new insights into the problem which we will try to make use of in our revision of the State-of-the-Art Review.

Maekawa

Most of the presentations during this Conference have been about operational control, integrated systems, and so on. However, I would like to give my views on future directions for information systems. As I reported yesterday, my major concern for the future of information systems is to establish or to formalize the structure of systems, by considering the following three points, that I believe to be very important and that must be taken into consideration.

1) What are the needs and the expectations for the information systems desired by companies? As you know, these vary greatly under the influence of business activity, social problems, political affairs, foreign affairs, and so on. The development of an information system that will work well under these various influences must be planned.

2) In the traditional design of automation, it seems to me that the designer made his great effort to realize a system that mechanized jobs done by man. But, I think the automated system of the future must be designed on the basis that man undertakes only those jobs that the automation system cannot do.

3) The final point relates to the previous two points. We must establish new programs for the education and training of people in the area of information systems in order to achieve systematized and effective computerization of information systems.

Cheliustkin

Thank-you for attending this discussion and for your comments. You have to remember that what we presented represents only a preliminary draft of the State-of-the-Art Review and we expect to improve it as much as possible with the help of your comments. Unfortunately, we will probably not be able to respond to some of the remarks because we do not have enough information.

During our visits to various steelworks we talked with the people who were responsible for implementing these systems. Mainly, we wanted to find out what were the general ideas behind these systems and what changes had been required in order to implement the integrated and computerized system. In the newly constructed works the implementation and improvement of the systems tended to be carried out step by step.

The remarks made by Maekawa about the people in the system are very important. A surprising thing that we found was that the systems are maintained by very young people. For the new systems, modern technologies and computer knowledge was needed and the steelworks recruited young people from the universities to perform these tasks.

I would again like to thank everybody who participated in our Conference. We will send you, as soon as they become available, a copy of the proceedings of this Conference combined with the final version of the State-of-the-Art Review of Integrated Systems Control in the Steel Industry. Thank you.

Appendix 1

Steel Companies and Research Institutes Visited for the State-of-the-Art Review

VISIT TO STEEL COMPANIES AND INSTITUTIONS

The members of the Integrated Industrial Systems Project organized visits to steelworks and research institutes in various countries in order to obtain information for the State-of-the-Art Review. There were a number of factors that influenced our selection of places to visit. First, we wanted to visit works that provided examples of advanced practice in various aspects of computerization and integrated systems control, that is, companies that were at the "leading edge" with respect to systems integration. Second, we wanted the survey to be representative in the sense that it reflected responses from some small steel producers as well as the world leaders, nationalized as well as privately owned companies, and systems operating under planned as well as market-oriented economies. Finally, we included in our itinerary visits that were prompted by expressions of interest in our project efforts.

In order to make the visits more productive, we prepared a list of questions which were sent to the companies in advance of our visits. In this way, people in the various steelworks were prepared to discuss the specific problems of our interest.

In addition to the steelworks, we visited several institutes dealing with research and design of computerized systems for the steel industry. Additional information was obtained by discussing different topics with the specialists from these institutes. This increased the scope of the State-of-the-Art Review. On the whole, we visited 35 enterprises and research institutes in 11 countries. These are listed below.

Australia

The Broken Hill Proprietary Co. Ltd.

Austria

Vöest-Alpine - Linz Works
Montanistische Hochschule (Leoben)

Bulgaria

Kremnikovici Works
Institute CNJKA

Czechoslovakia

SONP - Kladno Works
VSZ Kosice Works
NHKg - Ostrawa Works
Institute INORGA - Praha

Federal Republic of Germany

August-Thyssen Hütte A.G.
Duisburg Works
Fr. Krupp Bochum Works
Betriebsforschungsinstitute BDEh (Dusseldorf)
Siemens Head Office - Munich

German Democratic Republic

Bergakademie (Freiberg)

Japan

Kawasaki Steel Corporation
Mizushima Works
Kobe Steel
Kakogawa Works
Nippon Kokan
Fukuyama Works
Nippon Steel Corporation
Kimizu Works
Sumitomo Metal Industries
Kashima Works
Japan Iron and Steel Federation (Head Office)

The Netherlands

Estel Hoogovens Works

Union of Soviet Socialist Republics

Cherepovetz Works
Novo-Lipezk Works
Institute CNIICA, Moscow
Institute for Control Sciences, Moscow
Institute TNIISA, Tbilisi
Institute for Steel and Alloys, Moscow

United Kingdom

British Steel Corp. Headquarters - Birmingham
Rotherham Works
Scunthorpe Works
Lancashire Works

United States

Bethlehem Steel Co. - Bethlehem, Pennsylvania
United States Steel Corp. - Pittsburg, Pennsylvania
Republic Steel Corp. - Cleveland, Ohio
Inland Steel Corp. - Chicago, Illinois
Purdue University - Lafayette, Indiana

Appendix 2

Integrated Industrial Systems (IIS) Project: Questionnaire on the State-of-the-Art Review Covering Integrated Industrial Production Planning and Control Systems

OBJECTIVES

- To establish a body of knowledge concerning the methods and procedures used by advanced industrial companies for long-range planning, production planning, scheduling, and control.
- To meet and develop a rapport with scientists and industrialists throughout the world in order to ensure IIASA's work is realistic and pertinent. It is further hoped that such contacts will result in people from many different backgrounds coming to spend some time at IIASA.

INTRODUCTION

The word "planning" is frequently used regardless of the time scale referred to and the degree of detail being considered. Planning over long time scales right through to planning actual production can be thought of as a continuous process in which the degree of detail increases as the period being planned approaches in time. At any particular stage there is a limit to the degree of detail it is sensible to work with owing to the inherent uncertainties and varying conditions. This continuous process is usually divided into stages for convenience, for example, long term, medium term, annual, etc.

IIASA's IIS Project team is studying these planning procedures and also the hierarchical organizational structures (involving both people and automated equipment) necessary both to perform the planning activities and to ensure that the plans are carried out in practice. While it is inevitable that some interest will be shown in the interface between production planning and scheduling systems and process control equipment, it is not the intention to study process control itself.

DISCUSSION TOPICS

General Structure of the Planning Process

- How many stages is the planning process divided into and what time scales do they each cover?
- How frequently is each stage performed?
- What is the relationship of each stage to the others?

For Each Stage Identified in A Above

Scope

- What is the scope of the stage?
- What are its limiting characteristics in terms of time, works area covered, factors considered, and degree of detail?
- What are the objectives and how are they determined?
- What measures and criteria are used to determine success or failure?

Planning

- What does the planning/scheduling process consist of?
- What is (are) the end product(s)?
- What type of people are involved?
- Which activities are computer assisted and to what extent?
- What mathematical or modeling techniques are employed (both optimizing and deterministic), and for what purpose?

Reviews or Revisions

- How often are plans/schedules reviewed before actual implementation?
- To what extent are such reviews likely to cause alterations to existing plans/schedules?

- What other planning/scheduling stages are likely to be affected by a review at this stage?
- Apart from regular reviews, what other types of events could cause a review to take place?

Implementation

- How is a given plan/schedule actually implemented?
- Who is involved and to what extent have they freedom to adjust the plan/schedule?
- What are the relevant time scales?
- What aspects are computer-aided and to what extent?

Feedback

- What type of feedback and criteria are used to adjust the plan/schedule actually during implementation?
- How are any necessary adjustments effected?
- In what manner and to what extent is feedback used to influence previous planning stages?

Hierarchical Organization

In the context of the previous questions and topics an organizational control structure is implied.

- In terms of people, sections, departments, equipment, etc., how do the planning/scheduling activities fit in to the company organizational structure?

Company Opinion of Existing Planning System

- How did the company come to choose or develop the existing system?
- Is the company generally satisfied or dissatisfied with the current system?
- What are considered to be its strengths and weaknesses?
- Are there any plans for changes or further development of of these systems?

Company and Works

We hope to have a brief description of the company and the nature of its works and products so that the main body of questions can be appreciated in the correct context.

Computer Equipment

Where computers are being used, a brief description of their main characteristics would be helpful.

Appendix 3

Conference on
Integrated Systems Control in the Steel Industry

Agenda

June 30 - July 2, 1975
Wodak Conference Room

Monday morning, June 30

10:00	Registration	

Monday afternoon, June 30

SESSION 1: I. Lefkowitz, Chairman

14:00	Opening Remarks	R. Levien
14:20	Background of the Integrated Industrial Systems Project	I. Lefkowitz
14:40	State-of-the-Art Review Planning and Scheduling	D.H. Kelley
15:40	Discussion	
16:00	State-of-the-Art Review Production and Operations Control, Systems Integration	A. Cheliustkin
17:00	Discussion	

Tuesday morning, July 1

SESSION 2: D.H. Kelley, Chairman

9:00	Integrated Systems Control: The Purdue Experience	T.J. Williams
9:45	Discussion	
10:00	On Some Experiences with Production and Process Control in the Steel Industry	M. Knotek
10:40	An Example of a Schedule Model in an Integrated Control System	G. Surguchev
11:10	Discussion	

11:40	The Role of Simulation in the Implementation of an Integrated Systems Approach	B. Mazel
12:00	Simulation of Material Flow in LD Steel Making Plants	M. Watzenböck
12:30	Discussion	

Tuesday afternoon, July 1

SESSION 3: T.J. Williams, Chairman

14:30	State-of-the-Art Survey--Interpretive and Generalized Aspects	A. Cheliustkin
15:10	State-of-the-Art Survey--Conceptual Framework and Hierarchical Control Approach	I. Lefkowitz
16:10	Discussion	
16:30	A Structure for On-Line Dynamic Coordination	W. Findeisen
16:50	Discussion	
17:00	Integrated Production Planning and Control Systems in the Iron and Steel Industry	H. Pötzl
17:20	The Current Status and Future Aspects of Management Information Systems	Y. Maekawa
17:40	Discussion	

Wednesday morning, July 2

SESSION 4: B. Mazel, Chairman

9:00	Integrated Industrial Systems and Environmental Management	Y. Sawaragi
9:30	Inpact of Environmental Constraints in the Steel Industry	K. Ito
9:50	Plant Maintenance in the Iron and Steel Industry: Highlights in Systems Control	J. Wolfbauer
10:20	Discussion	
10:50	Application of the Hierarchical Multilevel Concept to Integrated Control Systems in Machine Building	J. Hatvany

11:20	Integrated Systems Control in the Chemical and Energy Industries	J. Valdenberg
11:50	Discussion	

Wednesday afternoon, July 2

SESSION 5: A. Cheliustkin, Chairman

13:30	Panel Discussion
	Summary and Conclusions

Appendix 4

LIST OF PARTICIPANTS

Austria

Dipl. Ing. Dr. H. Hübner
Institut für Betriebswirtschaftslehre
und Innovationsforschung
Universität Innsbruck
Innrain 82
6020 Innsbruck

Dipl. Ing. Kahler
Gebr. Böhler und Co.
AG. Werk Kapfenberg
Postfach 10
8605 Kapfenberg

Dr. Hermann Kopetz
VÖEST-Alpine Linz
Prozessrechenzentrum
4045 Linz

Dipl. Ing. Fred Margulies
Österreichische Studiengruppe
Automation und Industrielle Arbeitnehmer
Deutschmeisterplatz 2
1013 Vienna

Prof. Dipl. Ing. Albert F. Oberhofer
Institut für Wirtschafts- und
Betriebswissenschaften der Montanistischen
Hochschule Leoben
8700 Leoben

Dipl. Ing. Pink
Gebr. Böhler und Co.
AG. Werk Kapfenberg
Postfach 10
8605 Kapfenberg

Mr. H. Pötzl
Institut für Wirtschafts-
und Betriebswissenschaften
Montanistischen Hochschule Leoben
8700 Leoben

Mr. Rolle
IBM Roece Inc.
Vienna Branch
Obere Donaustrasse 95
1021 Vienna

Dipl. Ing. Töglhofer
Gebr. Böhler und Co.
AG. Werk Kapfenberg
Postfach 10
8605 Kapfenberg

Prof. H. Trenkler
Montanistische Hochschule
8700 Leoben

M. Watzenböck
IBM Roece Inc.
Vienna Branch
Obere Donaustrasse 95
1021 Vienna

Dr. G. Wieser
Österreichische Studiengruppe
Automation und Industrielle
Arbeitnehmer
Deutschmeisterplatz 2
1013 Vienna

Dr. J. Wolfbauer
Montanistische Hochschule Leoben
8700 Leoben

Bulgaria

D. Boyadziev
c/o Prof. H. Hinov
The National Centre for Cybernetics
and Computer Techniques
Slavjanska 8
Sofia

Bulgaria (cont'd)

D. Dimitrov
c/o Hinko Hinov
The National Centre for Cybernetics
and Computer Techniques
Slavjanska 8
Sofia

I. Shishkov
Central Research Institute
for Computer Automation
Sophia

Czechoslovakia

Mr. Jelinek
c/o Dr. T. Vasko
The Committee for the IIASA of
the Czechoslovak Socialist Republic
Slezska 9, Vinohrady
Prague 2

M. Knotek
INORGA
Latenska 17
Prague 1

Mr. Kyselowic
c/o Dr. T. Vasko
The Committee for the IIASA of
the Czechoslovak Socialist Republic
Slezska 9, Vinohrady
Prague 2

Federal Republic of Germany

Ing. Bruch
Verein Deutscher Eisenhüttenleute (VDEh)
Postfach 8209
4, Düsseldorf 1

Dr. Karl
Gesellschaft für Kernforschung m.b.H.
Postfach 3640
75 Karlsruhe 1

Federal Republic of Germany (cont'd)

Dr. Stams
Gesellschaft für Kernforschung m.b.H.
Postfach 3640
75 Karlsruhe 1

Hungary

Mr. A. Benczur
Computer and Automation Institute
Hungarian Academy of Sciences
Kende u. 13-17
1502 Budapest XI

Dr. J. Hatvany
Head of Division of Discontinuous Processes
Computer and Automation Institute
Hungarian Academy of Sciences
Kende u. 13-17
1502 Budapest XI

Mr. B. Kovacs
Computer and Automation Institute
Hungarian Academy of Sciences
Kende u. 13-17
1502 Budapest XI

Italy

Ing. de Gregorrio
Via Marcello Garosi
98 Rome

Japan

Mr. Yoshihiro Maekawa
General Manager
Headquarters Systems Development Section
Information Systems Dept.
Nippon Kokan K.K.
1-1-2 Marunouchi
Chiyoda-ku
Tokyo 10

Japan (cont'd)

Mr. Ohara
The Japan Iron and Steel Federation
European Office

Prof. Y. Sawaragi
Department of Applied Mathematics and Physics
Faculty of Engineering
University of Kyoto
Yoshida-honomachi, Sakyo-ku
Kyoto 606

The Netherlands

Mr. Phaff
Koninklijke Nderlansche Hoogovens
En Stallfabrieken nv Ijmuiden
Amsterdam

Poland

Prof. W. Findeisen
Politechnika Warszawska
Wydzial Elektroniki
Instytut Automatyki
ul. Nowowiejska
Warsaw 10

United Kingdom

Mr. D.H. Kelley
British Steel Corporation
33 Grosvenor Place
London S.W.1

United States

Dr. C.F. Long
Homer Research Laboratory
Bethlehem Steel Corporation
Bethlehem, Pennsylvania 18016

United States (cont'd)

Prof. T.J. Williams
Purdue Laboratory for Applied Industrial Control
102 Michael Golden Hall
Purdue University
West Lafayette, Indiana 47907

Mr. R.L. Whitely
Homer Research Laboratory
Bethlehem Steel Corporation
Bethlehem, Pennsylvania 18016

Union of Soviet Socialist Republics

Dr. G. Kavalerov
Deputy Minister
Ministry of Instrumentation and Automation
Ogareva 5
Moscow K-9

Mr. Massalsky
Institute of Control Sciences
USSR Academy of Sciences
81, Profsoyuznaya
Moscow V-279. 117806

Dr. J.S. Valdenberg
Deputy Director
Moscow Central Research Institute
of Complex Automation (CNIIKA)
Olkhovskaja 25
Moscow B-66

Mr. Zwirkulin
Institute of Control Sciences
USSR Academy of Sciences
81, Profsoyuznaya
Moscow V.279. 117806

IIASA Participants

A. Cheliustkin
K. Ito
D.H. Kelley
I. Lefkowitz
B. Mazel
G. Surguchev