Modelling production management systems

Conference Reports

Modelling Production Management Systems

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This review of the IFIP working conference on "Modelling Production Management Systems", held in Copenhagen, August 29–31, 1984, attempts to show the threads in the actual development of the science of production control. The major aim of flexibility can only be achieved by simplification and decentralization of the control structure. This requires the introduction of adapted models for production control, organization analysis and information systems development. Simulation is a promising tool, but the introduction is retarded because of problems concerning the validation of simulation models and the integration of simulation models with production databases.

A revolution is taking place in industrial production systems. The old target of labour productivity is to be replaced by the new target of flexibility. The step to be made is comparable to the step from simple feed-forward power steering to advanced feed-back servo control. The application of mechanical power enables us to move heavy objects (e.g. cranes), but movements remain slow and imprecise. By using servo control techniques heavy objects can be moved quickly and accurately (e.g. robots). However, the design of an appropriate servo mechanism requires a correct model of the dynamic behaviour of the object to be controlled. What we lack is a model of the dynamics of production systems. From a dynamic point of view a production system seems to be chaos: everything is related to everything and the quality of all relations depends heavily on circumstances.

This picture gives the background for the IFIP working conference on Modelling Production Management Systems, that was held in Copenhagen from August 29–31, 1984. Production management, as an engineering discipline, is founded on partial, usually separate, models. *P. Falster* contends that a single integrated theory, treating the total topic as a scientific unity, is still missing [7]. The presentations at this conference show some clear threads, which indicate the direction in which fundamental laws for production management should be focussed. Important themes covered at the conference were: simplification, modelling, decentralization, simulation, data modelling and socio-cultural aspects of production systems. This report attempts to show the joining threads and the coherence of the different contributions to the conference. The fact that it does not pay attention to the gaps and conflicts between the different approaches, does not mean that there was no discussion between the participants. For that discussion we refer to the proceedings of this conference [7].

1. Flexibility

According to *I. Inoue and Y. Yamada* [10], flexibility in production systems is defined as "The ability to adjust the system to external and internal changes".

Even when flexibility is the main target, inflexibilities have to be chosen consiously, noted *J.W.M. Bertrand* [1]. He said that the two main sources of inflexibility are the manufacturing technology and the control system. It is the task of production management science to eliminate undesired inflexibilities due to the control system.

It is clear that there is a positive correlation between flexibility and complexity of control. Useful flexibility is impossible without appropriate control. It is impossible to design a complex control system based upon a weak control theory. This implies that there are two ways to improve flexibility:

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1. Try to simplify the system in order to simplify the control problem,
2. Try to develop adequate models in order to be able to analyse the system and to enhance control theory.

2. Simplification

J.L. Burbidge [3] believes that the only effective way to simplify production control is to simplify the material flow system. In his presentation *Burbidge* postulated six laws of production system design:

1. *Law of Gestalt:* "The whole is not the sum of its parts and a set of sub-optimum solutions can never produce a true optimum solution". Most of our present production systems break this law because they are a sum of sub-optimum solutions, designed by specialists for marketing, purchasing, product design, production planning etc.
2. *Law of Material Flow:* "The efficiency of a production system is inversely proportional to the complexity of its material flow system". Most production factories today are organized in units which specialize in different processes (process organization). Via Production Flow Analysis they can be reorganized to "product organization", which greatly simplifies the material flow system.
3. *Law of Prescience:* "It is not given to human beings to foretell the future". Most existing production systems ignore this law by basing production on long term sales forecasts. Due to unavoidable changes they suffer from high and partially obsolete stocks. When regulating the material flow by series of short term programmes (Period Batch Control), production will only cover actual needs.
4. *Law of Industrial Dynamics:* "If demand is transmitted along a series of inventories using stock control ordering, then the amplitude of the demand variation will increase with each transfer". Most production industries today still ignore this phenomenon (first reported by J.W. Forrester, twenty years ago) and rely on chains of independent retailers, wholesalers and factory stores, each using stock control ordering.
5. *Ordering Cycle Law:* "If different components made in a factory are ordered and made to different cycles, they will generate high amplitude and unpredictable variations in both stocks and load". The reason for this is that the peaks and troughs of the many different component stock cycles drift into and out of phase. This points to the need to use single cycle ordering systems.
6. *Law of Connection:* "A given direction of change in the value of any production system variable will induce, or be induced by, a given direction of change of at least one other system variable". A first attempt to codify these relationships indicates that a change from process to product organization and from multi to single-cycle ordering is desirable.

According to *Burbidge*, a production system should be designed so that each product passes a minimum of production stations (Fig. 1). When production facilities are grouped according to technology (as conventional systems are), the number of stations can become very high because a product has to pass the same stations repeatedly. By grouping facilities according to logical production phases (group technology), a much simpler product flow will result. While the number of facilities and the number of detail production steps remain the same, the number of dependencies between groups is minimised and so is the number of decisions to be taken.

Some remarks have to be made with respect to simplification. A given system has a given number of atomic parts with a given number of interrelationships. In other words, a given system has a given complexity, and simplification can only mean hiding complexity (unless the system contains redundant relations). From systems theory two ways of abstraction are known to hide complexity:

1. Forming subsystems by hierarchical decomposition, which means recursively dividing the whole into parts with minimal mutual interdependence.
2. Forming aspect systems by abstracting all details that are irrelevant to the respective aspects.

The structuring of a company in divisions, departments and groups is an example of hierarchical decomposition. The financial system, the product design system, the production facilities maintenance system and the goods flow system are all examples of aspect systems of a company.

It should be noticed that simplying one aspect often means that complexity is not removed from the system, but is just moved into another aspect. When, for instance, the goods flow system is simplified by grouping machines according to production steps instead of grouping them according to technology, complexity is moved into the product

Automated Production Control

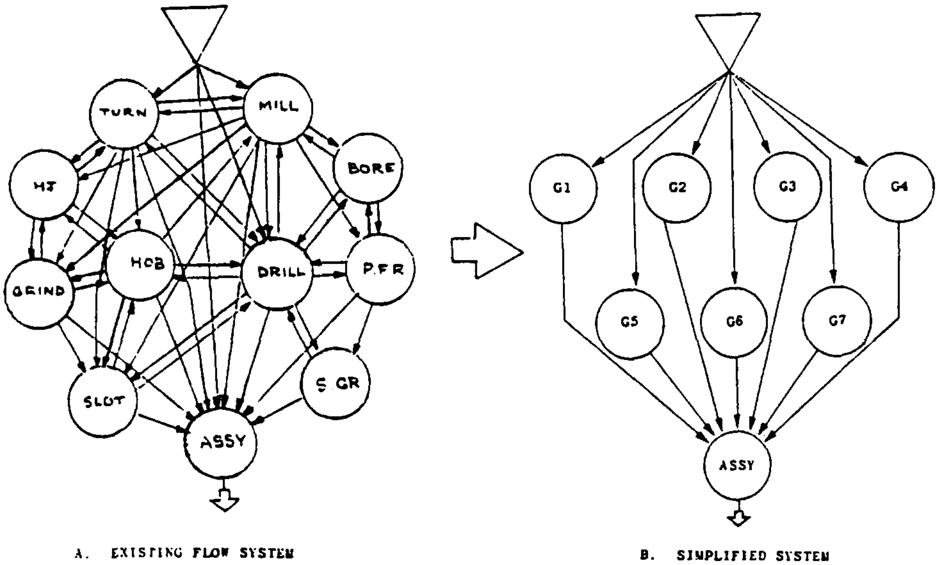

Fig. 1. Simplification of the flow network [3].

design system. This can be explained by the fact that the decision to group machines according to logical production steps is based upon knowledge about the product design. That implies that product design becomes less flexible and more complicated, because for future designs one has to take into account the actual grouping of machines. If, however, no relevant changes in product design are anticipated, this is a profitable choice, since complexity is moved from a dynamic to a static aspect.

3. Hierarchy

J.W.M. Bertrand [1] pointed ont that hierarchically structured control systems are based on the assumption that complexity should be reduced by defining self-contained subsystems with clear and well-defined operational characteristics.

In a hierarchical control system the control problem is split up into a number of levels. For each level the control problem is divided into a *visible* part, the coordination between the elements of that level, and an *invisible* part, the internal coordination of the elements. The art of systems design is to group the elements in such a way that only just as much complexity remains unhidden as can be captured by a sufficiently intelligent human being. Hierarchical decomposition does not mean simplification, but is only a way of managing complexity.

3.1. Centralization-Decentralization

Two types of hierarchy can be distinguished: centralized and decentralized.

In a centralized hierarchy thinking is top-down. The whole has been split into smaller parts because the job is too bulky to be performed by one person, but initiative and authorization come from the top. Lower level tasks are supposed to be strictly defined from higher levels. Tasks are delegated, not because the higher level is unable to perform that task, but only because it has more important things to do. Vertical coordination is only in terms of orders: lower level tasks are fully dependent on their higher level. *I. Inoue and Y. Yamada* [10] observed that in a decentralized hierarchy thinking is bottom-up. The whole has been split into smaller parts because the process is too complex to be managed by one person. Initiative is expected from lower levels and lower level tasks are defined in terms of means, ends and constraints. It is recognized that lower level, tasks require other capabilities than higher level tasks, because different levels take different types of decisions. Vertical coordination is in terms of constraints, proposed by the higher level, that should be explicitly accepted by the lower level. All tasks are given maximal autonomy. Only in the decentralized case can the hierarchy simplify the control problem for the top, because in the centralized case the top management still has to understand and define every detail of the lower levels. Centralized hierarchies cannot be flexible, since too many details have to be prescribed in rules.

3.2. Information Systems and Decentralization

According to *Inove and Yamada* [10], the factor that plays the main role in achieving flexibility is man.

They feel that computerised systems were developed too much from a centralistic point of view: "The system builders have a tendency to take the initiative, because they have strong ideas that they understand everything about production..." "The system is designed to include all the possible functions and so becomes big in size"; "The system wrests away the initiative in activities of system practitioners, rather than supports them".

Inoue and Yamada noted that the reasons rapid processing of massive amounts of data does not represent the solution for production contol problems are that:

- Information that can be converted into EDP data is limited and biased,
- Strong coupled systems have little adaptability to a rapidly changing environment,
- There is often a discrepancy between reality and the state that the systems thinks it should be (data are inaccurate and decisions rules inappropriate),
- Men feel reluctant to accept the results produced by the system,
- Learning opportunity is minimised, experience is not accumulated nor is intuition polished.

The conclusion from these remarks was that the existing habit of designing production control systems as well as the supporting information systems from a topdown/centralistic way of thinking, should be changed to a bottom-up/decentralistic approach.

3.3 Decentralistic Methodologies

"Shop floor control–Fabrication's Big Brother?" Under this motto *R. Guendling and S. Augustin* [9] proposed a typically decentralistic design method. The design method is bottom-up:

Step 1. Designing the necessary functions of shopfloor control.

Step 2. Starting off with the requirements of the functions of Step 1 on the design of middle-range planning.

Step 3. Starting of with the requirements of the functions of Step 2 on the design of long-range planning. Moreover, the approach is directed towards autonomy of functions:

Step 4. Assigning the respective responsibilities to the functions of shop-floor control and defining a clear area of competence for each responsibilitie.

Step 5. Starting of with the boundaries of the areas of competence defined in Step 4 one assigns responsibilities to the functions of middle-range planning and defines a clear area of competence for each responsibility.

Step 6. Idem for long-range planning.

Augustin and Guendling [9] pointed out that there is a distinction between the synchronization of fabrication processes and the synchronization of staff members. The first is a technical problem and the second an organizational problem. But the first one can only be solved after the second. It requires a clear assignment of responsibilities and liabilities, which is the same as defining the degree of autonomy of each function. This principle is manifested in the idea that a production order is no longer a "command" from order planning to fabrication management, but a "treaty" between the two parties, which is the result of a request for delivery that is confirmed after eventual negotiation. The conclusion is that correct synchronization, resulting in low stock levels and short throughput times, can only be achieved if ordering is carried out in full autonomy of shop floor control (Fig. 2). Overprotection of shop floor control by order planning (Big Brother) will provoke high stock levels as the staff members try to load their fabrication processes up to the maximum (without consideration of the rates of other processes).

3.4 Decentralization in Practice

G. Tideman-Andersen [15] reported on a practical application of the same principle on a different

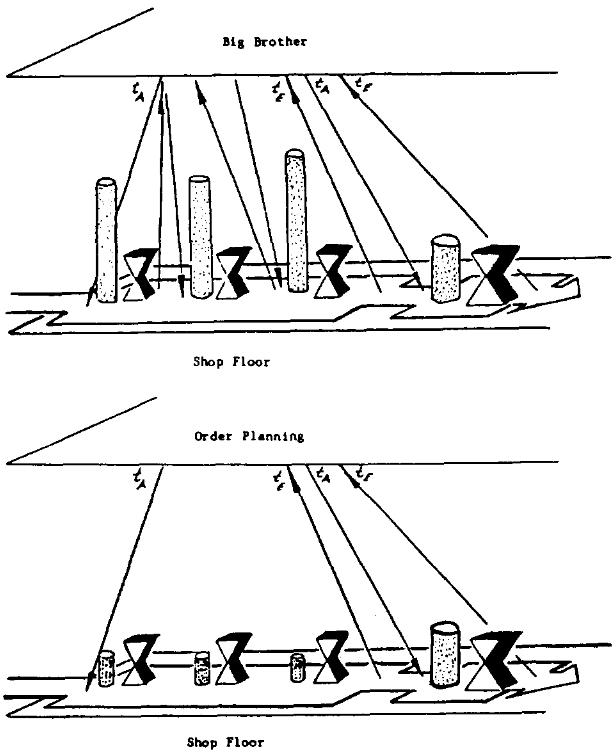

Fig. 2. Effect of "Big Brother" Control [9].

level. First the semi-centralized organization of a Norwegion electronic company was changed into a decentralized organization with autonomous profit-centers. After that, the EDP department started to implement a decentralized PMC-system. Thereby the responsibility for development, maintenance, data-accuracy and use of the system should be clearly defined and linked to the end users organization (profit center). As a result, each profit-center was assigned its own database, whereby only some aggregate and general data were kept in a central database.

Application of the decentralization principle on a lower level was reported by *T. Takeuchi* [14]. An on-line real-time distributed shop floor control system was implemented to control a job shop for small batch production. The system was implemented on micro-computers at both manufacturing units and at the shop control center, using a LAN (Local Area Network) to realize high speed communication among the microcomputers. The system deals with management information as well as with technical information. Each micro-computer was given a high degree of autonomy in reacting on changes as rushorders and machine tool failures. A centralized solution would have caused overload of the communication network. The example shows that decentralization can be a prerequisite for flexibility, not only for sociocultural, but also for technical reasons.

The distinction between decentralization and distribution is not always maintained. Distribution is the physical spreading of system parts over a number of locations. Decentralization is the logical spreading of responsibilities over a number of functions on different hierarchical levels. The system described above is an example of distribution (computers and memory at different locations) as well as of decentralization (local responsibilities).

According to *C. van Swichem* [13], decentralization will have consequences for the organization and internal control of automated information systems. In centralized systems all technical and procedural responsibilities are located in the EDP-department. In a decentralized structure part of the technical and all of the procedural responsibilities are moved to the user. *Van Swichem* noted that this complicates the task of maintaining a homogeneous, consistently well functioning system.

4. Modelling

The atomic parts of the production system are very well known: they are the individual machines, or the separate production steps, between which a waiting time for the product can occur. Up until now attention has mainly been directed towards the technology of the separate steps. Only since flexibility has become an important goal and throughput time has been recognized as the greatest enemy of flexibility, the problem of coordination between steps has become a hot issue. The difficulty is that the number of steps that has to be regarded in connection is too large for a human to understand. That is why we need a way to structure the elements into black boxes in order to reduce complexity. Such a way of structuring is called a model. Several models were proposed at the conference.

A search for a "production management concept" was described by *A. Dam* [4]. The motive is that existing models are too fragmentary. An example, *Dam* pointed out, is the simple systems control model, which splits the whole in a controlling and a controlled system. This model is not very useful if the controlled system is changing because of new technology, new product designs and job-enrichment actions. It is not surprising that many standard systems, based upon this model and implemented in the last ten years, did not meet their expectations. "Effective production management presupposes the integration of the controlling and the controlled system". According to *Dam*, a method for developing a production management concept should contain the following steps:

1. Analyze the product market conditions and the production technology,
2. Define the mission of production given by the external conditions, the internal constraints and the declared goals,
3. Use a means-end approach to define a rough structure by dividing the overall missions of production into several submissions,
4. Identify critical issues for each submission,
5. Develop a rough production management concept.

J.W.M. Bertrand [1] presented a methodology for designing hierarchically structured production control systems for complex production situations. The production control problem is split up into the following levels:

1. Reconcile production limitations and market needs by periodically generating a Master Plan,
2. Generate inputs to the production units, based on the Master Plan and aiming at coordination of the production units,
3. Control the actual inputs to each production unit, based on its internal state and on economic production.

According to *Bertrand*, the lowest level in hierarchy is the production unit: a combination of capacity types, operations and materials, that is self-contained from a manufacturing point of view. The next higher level is production unit control. Work orders are released to production units in order to realize a controlled workload for each unit. A too high workload causes long throughput times, a too low workload leaves a production unit too little freedom to realize production economics. *Bertrand* noted that feed-back of actual work in process information is essential for the production unit control function, Materials coordination is the mid-level control function in the model. It decides about norms for the workload for each production unit and the work order priorities per item. The function should aim at a minimum level of controlled stocks between production units. The top-level control is the master planning function, which generates a capacity use plan as input for workload norm calculation and a master production schedule as input for materials coordination (Fig. 3).

Master Planning requires aggregate system parameters to express the status of the production system, because it has no need to see all the details. Therefore the concepts of item echelon stock and capacity echelon stock are introduced. Here the problem arises that aggregate information is only a good basis for decisions if the details are well balanced. It is part of the autonomy of the lower level function to keep their affairs in balance. *Bertrand's* model also provides the concepts that enable the higher level to monitor the performance of the lower levels over a longer period of time.

In the previous section it was mentioned that computerized information systems are designed from a too centralistic point of view. Therefore we need new concepts to model decentralized information systems. Such a concept, called transaction, was introduced by *E. Eloranta* [6]. The components of a transaction are: logic, interface and knowledge. Logic can be viewed as a set of procedures, related to specific decisions, knowledge as a structured memory, containing the information relevant for the decisions, and interface as the possibility to exchange specific messages with specific other transactions. The transaction concept enables the decentralization logic and knowledge according to the decentralization of decision making (Fig. 4).

Transactions are isolatable because of the interfaces: as long as the interfaces remain the same, the logic or knowledge structure of a transaction can be modified, without affecting other transactions. Messages are used to trigger and synchronize transactions. *Eloranta* suggested that Petri-nets can be used to model the behaviour of networks of transactions.

The use of Petri-nets as a tool for modelling and analyzing Flexible Manufacturing Systems was discussed by *J. Favrel and K.H. Lee* [8]. Especially interesting in this context is that they presented a new method of hierarchical decomposition of Petri-nets.

Artificial intelligence concepts can also be in-

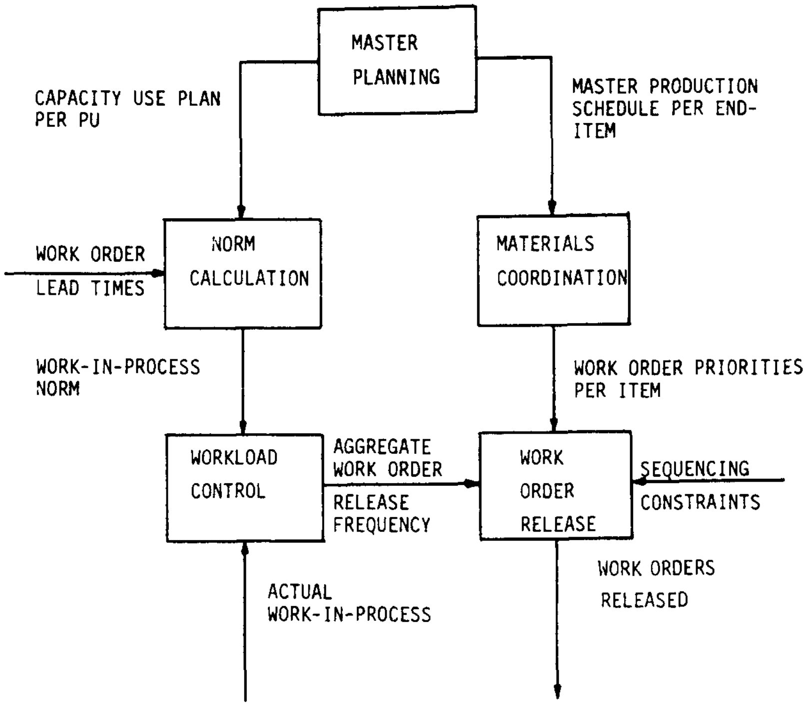

Fig. 3. Hierarchical Production Control Model [1].

corporated in a production control model. A fundamental concept of artifical intelligence is to build models of which the structure is similar to the mental structure of man. According to *D. Breuil, G. Doumeingts and C. Derard* [5], it is thus possible to give a computer some human abilities such as reasoning, learning and searching for solutions through heuristic rules. Computer systems of which the structure is similar to that of the mental structure, will be easier to cooperate with. *Doumeingts* noted that artificial intelligence concepts can be applied with, or without, special computer languages like Prolog and Lisp. The main element of the approach is that control rules are not specified in sequences of if..then..else decisions, but in sets of constraints that have to be satisfied simultaneously. Moreover, the possibility is recognized that constraints can be conflicting. In that case some less important constraints have to be overruled in order to obtain a solution. Therefore constraints should be associated with a weighing factor.

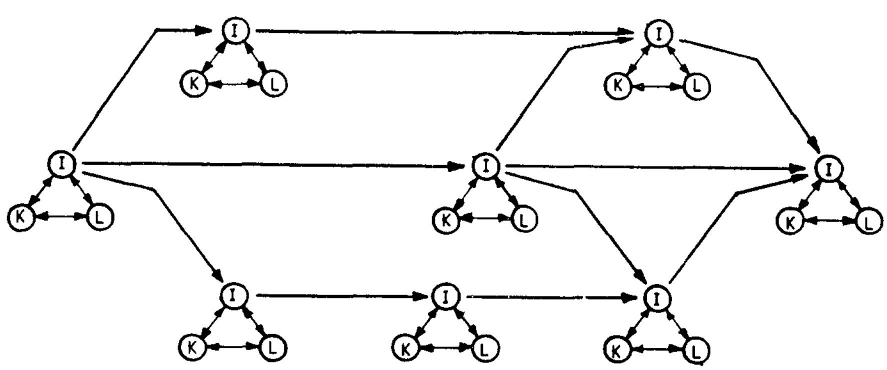

Fig. 4. A Decentralized Information System Modelled with Transactions [6].

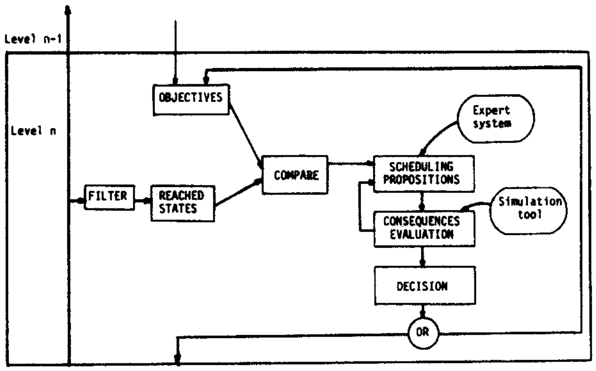

Fig. 5. Incorporation of Artificial Intelligence and Simulation in a PMS [5].

It is important that the system should not be expected to give the optimal solution, but simply an acceptable one. The expert system generates scheduling propositions, which can be evaluated using a simulation tool (Fig. 5). The user can then contribute his knowledge and acquaintance with the workshop and take the decision.

5. Simulation

Computer simulation is a powerful tool for evaluating alternative proposals. Many of the lectures presented underlined the importance of simulation for production control. Some lectures even stated that the incorporation of simulation tools is indispensable for a effective cooperation in production control between man and computer. According to *A. Coll, L. Brennan and J. Browne* [2], two types of simulation can be distinguished:
1. Structure Simulation: to evaluate alternative production system designs,
2. Process Simulation: to evaluate alternative control decisions.
A combination of these two forms, a simulation to analyze the effects of the use of simulation in an organization, was described by *W. Rzonca* [12].

Structure simulation is the most frequently applied technique. *T. Takeuchi* [14] observed that it is often used in FMS design, for instance in evaluating different sequencing algorithms. *J. Browne* [2] pointed out that the main problems with simulation are:
1. the long lead time from initial design to implementation of a model,
2. validation of simulation models,
3. difficulty in defining objective performance criteria to evaluate the results of various experiments,
4. interfacing simulation models with other production systems models (e.g. MRP-II systems),
5. the user interface.
These problems are probably due to the especially slow pace of introduction of process simulation. Yet the importance of process simulation for flexible production control was emphasized by different authors. In the trend towards decentralization more decision freedom is to be given to lower control levels. The problem according to *Inoue* [10], is to enhance, and apply the human experience and intuition, as well as to employ the increased amount of information and information processing power that is made available by computerized information systems. *Doumeingts'* [5] idea is that computers may propose a set of alternative solutions but ones that man has to decide. Process simulation can then be an important aid to evaluate the predictable consequences of alternative decisions. In the second place, it requires that the simulation model can be interfaced with the production systems database. *Browne* [2] noted that the problem here is that simulation languages are model oriented instead of data oriented. Ever since the introduction of computers for production planning, there have been ideas to use the production status database and the production planning programs for simulation to answer what-if questions. The idea is simply to run the planning program on a database copy with modified parameters, but the idea never worked very well because of the following difficulties:
1. handling multiple database copies, physically as well as conceptually,
2. analyzing a simulation result in the form of a vast database,
3. planning programs are deterministic and simulation should incorporate stochastic properties.
These problems show the importance of integration between database management systems and simulation languages. However, before that can be achieved, there should be an integration between database and simulation modelling concepts.

6. Data Models

The use of data models to evaluate software packages for production control was discussed by

J.C. Wortmann [17]. He specified the data model of the essential components in a hierarchical production control system and compared it with the implicit data models of a number of MRP-II based software packages. This comparison shows that none of the packages contains an element to represent the essential concept of hierarchy, so none of them is really appropriate to support the MRP-II philosophy.

Data models have been developed as a tool for database design. Driven by the need to abstract from physical properties of computers and from the logical properties of specific Data Base Management Systems software, data models evolved from database models to conceptual data models than can be used to describe the semantic structure of information. The relational data model is the first really abstract data model, but is rather poor in expressing semantics. Different semantic or conceptual models have since been developed, of which the Entity Relationship Approach (ERA) and the binary data model are two of the most influential examples. *D.C. Tsichritzis and F.H. Lochovsky* [16] feel that these models can be abstract and simple because they are based upon mathematical definitions. They are able to express in detail the semantics of some "universe of discourse", without the need to refer to any implementation dependent aspects, as, for instance, the choice between manual or automated information processing. Therefore these models are more than just a tool for database design. They are also a tool to draw formal models of abstract concepts in general.

Data models can be a very powerful tool in the production control environment since production control concepts are becoming more and more abstract from the physical properties of the production system. The way *Bertrand* [1] introduced aggregate concepts is an illustration of this. Since narrative descriptions of abstract concepts tend to be ambiguous and lengthy, a method to describe them in a formal way is very much needed.

A shortcoming of current data models is the inability to express dynamic properties and decentralization aspects. The concept of transaction, as presented by *Eloranta* [6], can be seen as a step forward with respect to this problem. Conceptual data models are also important for the integration of databases and simulation models. When the properties of a PMS are defined in a conceptual data model, a simulation can be modelled as a program that generates stochastic inputs to a given database of that model. This process will produce a result database of that model containing all the relevant data to analyze the performance of the simulation run. Analysis can be supported by standard query facilities.

7. User Interface

The use of computers to support real time decisions implies that non-EDP professionals have to operate the computer systems in an interactive way. That poses very high ergonomic requirements to the user interface. However there is still very little knowledge in this field, and it is clear that computer graphics will play an important role. An interesting example is the system for interactive sequencing with the use of computer graphics, presented and demonstrated by *K. Lund and S. Eriksen* [11].

Another important aspect of the user interface is the design methodology. Since there are so few formal laws to control the interface design, it is essential that the potential user plays an active role in the design. According to *E. Eloranta* [6], this requires a short design-implementation cycle as is possible with so-called prototyping techniques, which rely on software generators instead of high level programming languages.

Conclusion

The rising need for flexibility of production sytems implies a severe complication of the production control problem. We realize that an integrated production control theory is missing. The complexity of the control problem can be managed by designing decentralized hierarchical control systems. Decentralization is essential since higher level control functions can only master the problem if they have aggregate information to control aggregate parameters. This will only work if the balancing of the details can be left to the lower control levels (autonomy). Such systems can only be designed if the right concepts are available to define the proper aggregate production control parameters, The problem is that the available modelling concepts, especially those for information systems design are centralistic by nature, so they are not appropriate for mastering this problem.

The role of simulation techniques in production control will increase, especially in the support of operational decisions. Therefore, simulation programs will need access to production control databases, so it is essential that simulation modelling and data modelling techniques are integrated into one concept.

The mathematically founded abstract data models, as they have evolved from database theory, can be a powerful tool for integrating simulation models with databases, as well as for building formal models of abstract production control concepts.

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Advances in Manufacturing

An International Conference on Advances in Manufacturing (AIM) was held in Singapore from October 9–11, 1984. This event was organized and sponsored jointly by IFS (Conferences) Ltd., U.K. and by Singapore Exhibition Service Pte. Ltd., Singapore. AIM was co-sponsored by The Singapore Robotic Association.

The following topics were covered at the conference:

- Industrial Robot Technology
- Computer-Aided Design and Planning
- Computer-Aided Machining
- Tooling and other Aspects of Advanced Manufacturing Technology
- Advanced Welding Techniques
- Computer-Aided Inspection and Assembly.

We present below a report on the topical lectures delivered at this meeting on AIM.

Keynote Address

Developing Countries

I.S. Jawahir and *W.C.K. Wong* (P.N.G. University of Technology, Papua New Guinea) presented an overview of the manufacturing scene in devel-