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Educating Tomorrow's Manufacturing Systems Engineers Today*

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Today's manufacturing environment demands appropriately trained engineers and managers. The challenge facing educators is to provide the knowledge and understanding which appropriately conveys the magnitude, complexity and exhilaration of the manufacturing environment. A teaching approach developed at Aston University conveys such inherent characteristics through the use of simulation and commercial software within an extensive case-study. Students manage a simulated factory where the range of decisions that can be made and evaluated extend beyond those of conventional simulators and case-studies. This paper discusses how the approach is currently implemented.

INTRODUCTION

As all experienced operations managers know, there are but two simple devices necessary to run an operating unit—a crystal ball and a magic wand. In the absence of these, the present volume is offered to those engaged in that peculiar form of juggling, known as production or operations management. [1]

The above quotation aptly describes the situation faced by people working in the manufacturing domain. Since future production managers will attend manufacturing courses at universities and colleges, it also provides a suitable point to begin any discussion which considers how they should be educated.

The basic production activity in any organization could be considered simple; it is concerned with the organization of production so that the right products are made in the right quantities and at the right time. The reality, however, is complex. This complexity does not rest upon the individual issues involved but the number of interrelationships of the issues [2].

Production and operations management incorporates many diverse tasks that are interdependent and as a consequence make the function difficult to define succinctly. Descriptions and definitions do, however, exist [3]. What is clear from such definitions is that the operations function is concerned with aspects of the design, planning and control of resources for the production of goods. This involves both short-term (operational) and long-term (design, planning) business activities. These tasks do not take place in a vacuum; the production process is coupled to all the other business functions found in any manufacturing organization, namely finance, marketing, sales, design, purchasing and personnel. In addition these tasks extend outside the organizational boundaries to include both customer and supplier issues as well as those of competitors.

The competitive nature of today's world economy adds further complications. Greater flexibility and reduced lead-times are required so that organizations can respond to changing customer demands and expectations. It is essential, therefore, that companies use their manufacturing operations as a key competitive factor to win business. To manufacture competitively requires 'well motivated, skilled people with a continuous ability to learn' [4].

The challenge facing educators is to provide their students with the knowledge and understanding which appropriately conveys the magnitude and complexity of the manufacturing function. Not only must students understand the many techniques involved but how and when to apply them. Students need to be aware of the dynamic nature of the environment in which they are working and of the interrelationships involved in any decision or action they may make. More precisely, students need to experience the production environment.

WHICH TEACHING APPROACH?

The activities involved with managing a manufacturing facility take place in, and contribute to, an environment that is naturally complex and dynamic; these characteristics need to be reflected in the way manufacturing systems engineers are taught production and operations management. Traditional methods can fail to convey such inherent properties. This is not due to the lack of material but the manner in which it is presented [5].

Machinists would not learn how to operate a machine solely by reading the technical manual;

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they also need to practise what they have learnt. Similarly, students find it difficult to learn about the aspects of production control just by attending lectures or reading books. Improvements have been made whereby students gain practical experience of the theory [6]. However, learning and experience together are not necessarily effective. Theory needs to be linked to practice in such a way that it enhances learning.

An effective 'learning by doing' approach [7] involves a cyclical sequence of four elements: thinking–planning–experience–reflecting. These four elements involve thinking about the theory and the related areas, planning how to put the theory into practice, experiencing what happens when plans are carried out, and reflecting upon experiences in terms of what has happened and why.

The initial stage involves students gaining knowledge of the specialist areas and techniques involved in the field of operations management. Due to the problems associated with conveying the practical aspects of production management there is a tendency to fragment material and oversimplify issues. This mode of teaching will be easier but is limited: there is a tendency to stress techniques that are in themselves unimportant. Because production management does not take place in isolation it is the conceptual understanding of the total production system, including the component interactions, which needs to be emphasized.

Within the planning stage students need to apply their learning to a relevant practical situation, i.e. planning how to run a production facility. Conventionally this may have been covered by a series of tutorial problems in which, typically, a single technique is applied to a simplified problem. Such an approach fails to reflect the necessary trade-offs demanded by 'real' industrial problems. While a case-study approach may be successful in demonstrating the interrelationships, it only provides a static view at one particular point in time. It does not emphasize the dynamic aspects of the operations environment. Simulation can be used to correct this weakness; it provides the dynamics and time-phasing characteristics.

Students need to implement their own plans to gain experience of controlling a production system. Experience is considered to be the enhancement of knowledge resulting from observing the effects of decisions or plans. Typically, new decisions are based upon new data and plans, which are conditioned by previously implemented decisions. In most cases application knowlege is gained through experience at work. Because this can be costly both in terms of time and mistakes, students need to gain these experiences in a 'risk-free' environment. Again, simulation proves to be relevant. The use of simulation in the teaching of production management is not new [8, 9]. However, the use of simulation alone tends to simplify the environment, restrict the scope of the problem(s) and exclude human involvement. More recent developments [10] have sought to address these issues. Through an extensive computer simulation exercise students gain experience of making both strategic and operational decisions. However, a mechanistic view of the production environment is taken, which avoids the impact that 'people issues' have on operations.

In order to reflect on their experiences and thereby include them in any future plans or actions, suitable feedback is required. In the context of operations management the feedback mechanism must match the sophistication and complexity of the topic. This is unlikely to be achieved by comments on course work. It is more appropriate to provide performance analyses, stock reviews and cost reports.

Clearly, providing students with the knowledge, experience and thereby the understanding of manufacturing issues requires a multi-dimensional teaching approach—one that retains the power of simulation but adds a human dimension. This is only to be expected considering the nature of the environment.

THE CELL-12 CASE-STUDY

A novel teaching approach in use at Aston University provides an environment that conveys the complexity and magnitude inherent in manufacturing systems and reflects what happens in the 'real world'. The approach includes the use of simulation, commercial software systems and human interplay within an extensive case-study, and thereby extends the range of decisions that can be made and evaluated beyond those of conventional simulations and case-studies. Furthermore, the approach facilitates the 'learning by doing' cycle and is, therefore, considered to be effective. The remainder of this paper will discuss how this approach is currently implemented.

Background to the case-study

Teams (of four or five) inherit the management function of a factory cell called 'Cell-12'; their role is that of a manufacturing executive, answerable to the works director. Each team is given the same initial brief:

To improve the operational management of the cell's production by:

- the implementation of a material requirements planning (MRP) system;
- the implementation of modern manufacturing management principles.

Modern manufacturing management principles can be considered as the steps towards just-in-time (JIT), e.g. reliable plant, reduced inventory, flexible labour, total quality management (TQM), customer and supplier development. Although handed with the same brief, the interpretation is left with the individual teams.

The case-study lasts for 10 weeks of real-time and forms a substantial part of both an undergraduate manufacturing systems design/control module and a postgraduate integrated manufacturing systems course. The Cell-12 case-study complements an earlier case-study that is undertaken by final-year students and addresses issues of manufacturing systems design [11]. The participating students have varied backgrounds: undergraduates will have followed related courses in earlier years and some will have gained industrial experience from 'sandwich' periods with collaborating companies; postgraduates may have little or no experience of the manufacturing environment. The nature of the case-study means that this does not prove to be a problem.

The cell manufactures a family of four spindle assemblies which are made from two component parts: a spindle and a gear. This provides a product base of 20 part numbers: 8 bought-out and 12 made-in. Both the product structure and the range of products has been kept simple in order to allow teams to concentrate on the operational issues, which have not been simplified. Experience of running the case-study justifies this decision.

The manufacturing facilities include five lathes, four milling machines, two broaches, two presses, four grinders and a heat treatment process—as illustrated in Fig. 1. The equipment is typical of many organizations in terms of age, efficiency and reliability. Figure 1 also indicates the number and distribution of machine operators; at the start of the case-study all the operators are job/machine specific. Additional indirect staff include two inspectors, three craftsmen and two material handlers. The factory/cell operates a two-shift system with a basic week of 37.5 hours, although overtime can be introduced if required.

The important internal and external relationships involved in any manufacturing environment are present in this case-study. Departmental interrelationships are included, e.g. personnel, sales, marketing, purchasing and finance. The raw material is obtained from an outside source and the finished assemblies are subject to an external sales demand.

Cell management issues

On inheriting the management function of Cell-12 each team must decide how they will manage their cell in terms of the day-to-day operational issues, the implementation of the MRP control system and any additional cell development issues. It should be emphasized that the interpretation of the case brief is left with the individual teams; there is no set of prescribed tasks that teams should follow.

In order to assess the levels of production that can be attained, the teams need to determine the capability of the cell in terms of the capacities and efficiencies of machines and operators. Additional operational issues involve setting manufacturing policies, i.e. the master production schedule (MPS), manning levels, overtime, shift patterns,

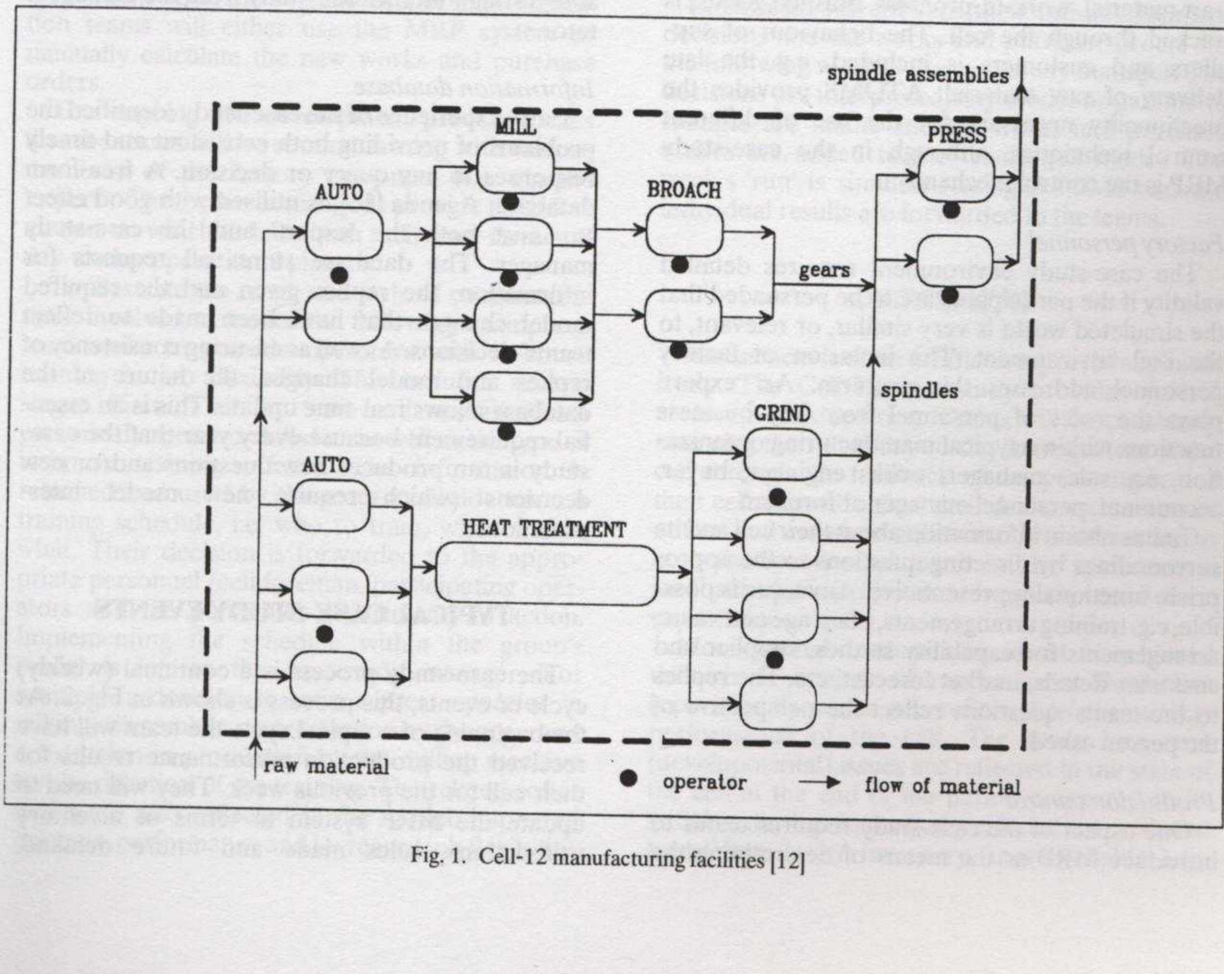

Fig. 1. Cell-12 manufacturing facilities [12]

subcontracting, stock levels. As in any operational unit there is a need to account for the dynamic and unpredictable events, e.g. breakdowns, supplier failure, sales order revisions.

The implementation of the MRP control system requires several issues to be addressed: the integrity of the manufacturing database needs to be ensured as well as determining how to manage the data-update activities. There are associated implementation issues such as achieving a reliable supply of raw material together with shorter and more consistent production lead-times.

Cell development issues include aspects such as operator retraining (e.g. quality or job flexibility), increasing resource efficiency (plant refurbishment or the purchase of new plant), or the development of customer and supplier relationships.

CELL-12 SUPPORT SYSTEMS

Simulation

Simulation is used to provide the dynamics and time-phasing characteristics found in the manufacturing environment. Cell-12 is modelled using a configurable factory simulator called ATOMS [13]. ATOMS is a batch manufacture-oriented simulator; it was originally developed (at Aston University) for use in manufacturing systems design and used in industry for that purpose. The simulation of the production process includes factors such as operator and machine efficiency, scrap, setting, breakdowns and repairs. Material (raw material, work-in-progress, finished goods) is tracked through the cell. The behaviour of suppliers and customers is included, e.g. the late delivery of raw material. ATOMS provides the functionality necessary for the use of different control techniques, although in the case-study MRP is the control mechanism.

Factory personnel

The case-study environment requires detailed validity if the participants are to be persuaded that the simulated world is very similar, or relevant, to the real environment. The inclusion of factory personnel addresses this problem. An 'expert' plays the roles of personnel from key business functions within a typical manufacturing organization, e.g. sales manager, works engineer, buyer, accountant, personnel manager or foreman.

Teams obtain information about their cell and its surroundings by directing questions to the appropriate functional representative. Any topic is possible, e.g. training arrangements, plant age and value, arrangements for capability studies, supplier and customer details, market forecast, etc. The replies to the teams' questions reflect the perspective of the person asked.

Production control

One aspect of the case-study requires teams to introduce MRP as the means of determining the cell's production and purchasing requirements. The MRP function is provided by UNIPLAN [14]—a commercial, PC-based manufacturing resource planning (MRP2) system.

The wide range of facilities offered by commercial systems, together with their procedures (necessary to achieve data integrity), can make them cumbersome to manage and daunting to use. For these reasons they are not widely used in case-studies. More simplified approaches (e.g. using a spreadsheet-based MRP system) can be expected to provide an efficient way of gaining an understanding of the principles involved. A similar understanding can also be gained through the use of standard tutorial exercises or case-studies. A real system, carefully configured and supported, allows the student to develop a deeper appreciation of the difficulties of applying these principles in practice.

Case-study manager/tutor

The case-study manager interprets both the operational and long-term decisions of each team; the decisions are translated into inputs and changes to their ATOMS model. Changes could include adjustment of model parameters or modification of the model structure. For instance a decision to refurbish a machine will incur costs, remove plant (and operators) from operation for 'x' days, tie up works engineering for 'x' days, result in a reduction in cycle-time variability and the probability of a breakdown.

Much of the academic tutorial support is available throughout the case-study from the manager/tutor.

Information database

Early experience of the case-study identified the problems of providing both consistent and timely responses to any query or decision. A free-form database, Agenda [15], is utilised with good effect to assist both the 'expert' and the case-study manager. The database stores all requests for information, the replies given and the required model changes that have been made to reflect teams' decisions. As well as ensuring consistency of replies and model changes, the nature of the database allows real-time update. This is an essential requirement because every year that the case-study is run produces new questions and/or new decisions (which require new model interpretations).

TYPICAL CASE-STUDY EVENTS

The case-study process is a continual (weekly) cycle of events; this process is shown in Fig. 2. At the beginning of a typical cycle the team will have received the production performance results for their cell for the previous week. They will need to update the MRP system in terms of inventory transactions, sales made and future demand.

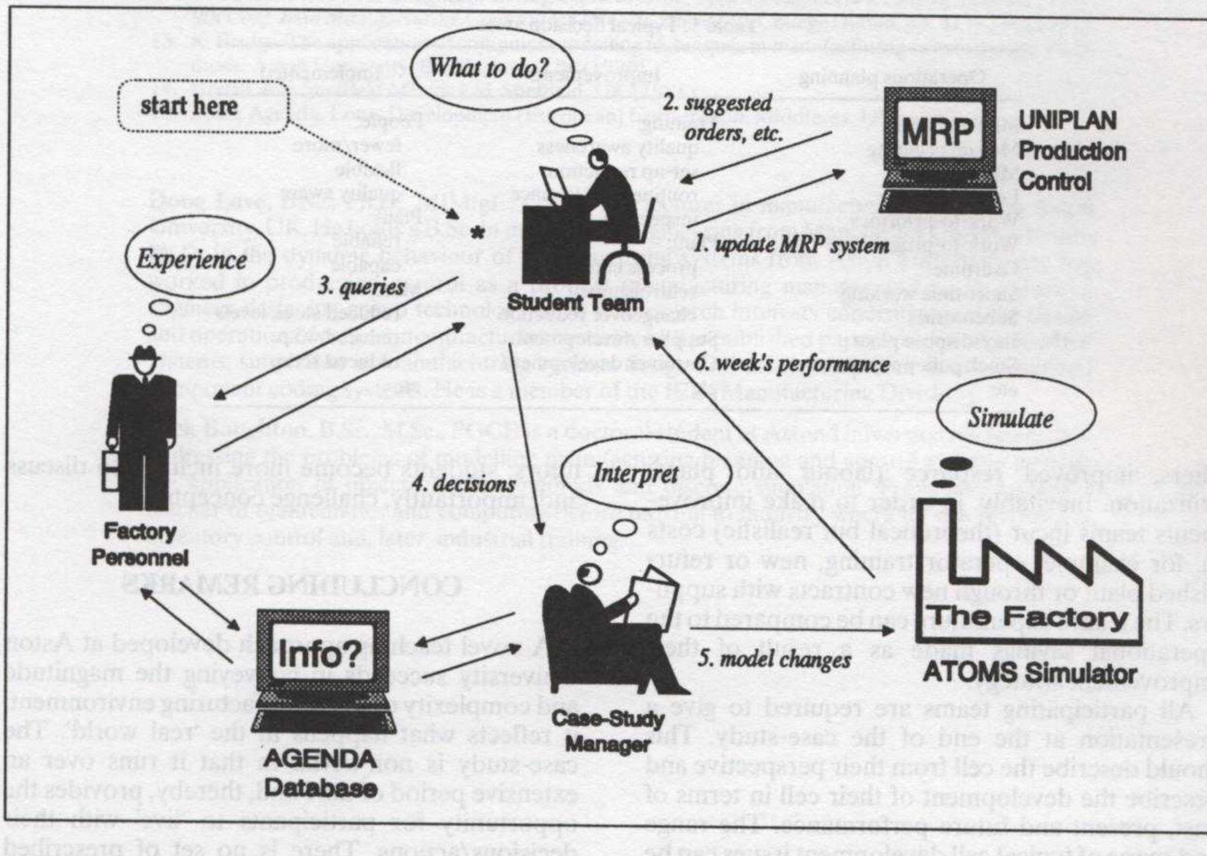

Fig. 2. The case-study process.

Dependent upon the current level of implementation teams will either use the MRP system or manually calculate the new works and purchase orders.

The ongoing cell development process means that the teams will be communicating with various members of the factory personnel (i.e. via the 'expert'). These communications provide the information on which to base both their long-term and day-to-day operational plans.

To illustrate the range and style of communications involved, consider the following example: a team seeks to provide operators with in-house training in job flexibility. This includes several stages. First of all the team will request (from personnel) operator skill data as well as the type of in-house training offered. The information is returned and used by the team to decide upon a training schedule, i.e. who to train, when and in what. Their decision is forwarded to the appropriate personnel (cell foreman, participating operators and the personnel department) to action. Implementing the schedule within the group's model is left to the case-study manager. For example, a decision to train a press operator in milling will result in no production by the press and a reduction in production by the milling machine for the duration of the training. The related softer issues are also reflected in the model: improved operator performance and increased job flexibility.

Each team will forward their cell development decisions and the works and purchase orders for the following week to the case-study manager. The decisions are interpreted, any model or parameter changes are made, and the works and purchase orders are added to the team's cell model. The week's 'run' is simulated using ATOMS and the individual results are forwarded to the teams.

ASSESSMENT

Assessment is often a difficult aspect of any case-study. The Cell-12 case-study provides several areas for consideration. Teams will be constantly assessing their own day-to-day management of the cell through the feedback of the performance of their cell; this will reflect their decisions in terms of output and resource utilization. It is interesting to note the reaction of teams to the performance feedback since it may not always represent their expectations.

More formal student assessment is achieved through a number of mechanisms. Short-term (operational) issues are reflected in the weekly performance of the cell. The more long-term (developmental) issues are reflected in the state of the cell at the end of the period compared to its initial state, e.g. improved performance, reduced lead-times, lower inventory, more reliable sup-

Table 1. Typical decision areas

Operations planning	Improvements	Implemented
MRP updates	Training:	People:
Manual ordering	quality awareness	fewer/more
MRP ordering	set-up reduction	flexible
Levelled MPS	routine maintenance	quality aware
Work-to-priorities	inspection	Plant:
Work-to-programme	Plant:	reliable
Overtime	process capability	capable
Short-time working	refurbishment	Material:
Subcontract	changeover reduction	reduced stock levels
Buy/dispose plant	Supplier development	reduced w.i.p.
Stock policy adjustment	Customer development	reduced scrap
etc	etc	etc

pliers, improved resource (labour and plant) utilization. Inevitably, in order to make improvements teams incur (theoretical but realistic) costs in, for example, operator training, new or refurbished plant or through new contracts with suppliers. The team's expenditure can be compared to the operational savings made as a result of their improvement strategy.

All participating teams are required to give a presentation at the end of the case-study. This should describe the cell from their perspective and describe the development of their cell in terms of past, present and future performance. The range and scope of typical cell development issues can be appreciated from Table 1. Although the initial state of the cell is the same for all teams, the final state reflects the different approaches taken. Both the style and standard of presentation is comparable to that expected in industry.

There are less quantifiable aspects which ought to be considered, perhaps not in terms of assessment but as benefits. The quality and scope of the enquiries to the 'expert' provides useful insight into the students' understanding of the problem domain. Furthermore, it is noticeable that closer communication is developed between students and tutors; students become more inclined to discuss and, importantly, challenge concepts.

CONCLUDING REMARKS

A novel teaching approach developed at Aston University succeeds in conveying the magnitude and complexity of the manufacturing environment; it reflects what happens in the 'real world'. The case-study is non-trivial in that it runs over an extensive period of time and, thereby, provides the opportunity for participants to 'live' with their decisions/actions. There is no set of prescribed tasks to follow nor are the problems that are considered restricted either in scope or depth. Furthermore, issues are not simplified or seen in isolation; through the supporting systems the dynamics and interrelationships are integral. The factory environment is 'realistic' and the case-study includes the important 'human' interactions which adds a dimension often overlooked.

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REFERENCES

1. A. Muhlemann, J. Oakland and K. Lockyer, *Production and Operations Management*, 6th edn, Pitman, London, p. ix (1992).
2. T. J. Hill, Teaching and research directions in production/operations management: the manufacturing sector, *Int. J. Op. Prod. Manag.*, 7(4), 5–12 (1987).
3. D. Bennett, C. Lewis and M. Oakley, *Operations Management*, Philip Allan, London (1988).
4. J. Neill, More to making it, *The Times Higher Education Supplement*, No. 1095 (29 October) p. 25 (1993).
5. J. A. Smith and J. L. Cox, Education for manufacturing industry: the rudimentary requirements from a student's viewpoint, *Comput. Ind. Engng*, **19**(1–4), 160–164 (1990).
6. S. K. Vajpayee and A. Jain, Teaching manufacturing as law/medicine, *Int. J. Appl. Engng Ed.*, 7(4), 258–263 (1991).
7. G. Gibbs and T. Habeshaw, *Preparing to Teach: An Introduction to Effective Teaching in Higher Education*, Technical and Educational Services Ltd, UK (1989).
8. J. H. Mize, *Production System Simulator (PROSIM V): A User's Manual*, Prentice Hall, Englewood Cliffs, NJ (1971).
9. G. Southern, A factory simulation model for teaching, *Int. J. Mech. Engng Ed.*, 7(4), 183–187 (1979).
10. W. L. Berry and V. A. Mabert, ITEC: An integrated manufacturing instructional exercise, *Int. J. Op. Prod. Manage.*, **12**(6), 3–19 (1992).
11. D. M. Love, Yoke-Flange Case Notes, Aston University, Birmingham, UK.

12. D. M. Love and N. J. Boughton, Giving manufacturing systems engineers a taste of 'real-life', *Proc. 9th Conf. Irish Manufacturing Committee* (*IMC-9*), University College Dublin, pp. 311–319 (1992).
13. K. Bridge, The application of computer modelling techniques in manufacturing system design, Ph.D. thesis, Aston University, Birmingham, UK (1990).
14. UNIPLAN, Sheffield Micros Ltd, Sheffield, UK (1986).
15. Lotus Agenda, Lotus Development (European) Corporation, Middlesex, UK (1990).

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