A DESIGN AND IMPLEMENTATION METHODOLOGY FOR HIGH VARIETY ELECTRONICS ASSEMBLY SYSTEMS

Dr David J Bennett
Aston University Business School
Innovation Design and Operations Management Research Unit
Birmingham United Kingdom

ABSTRACT

Small indigenous manufacturers of electronic equipment are coming under increasingly severe pressure to adopt a strong defensive position against large multinational and Far Eastern companies. A common response to this threat has been for these firms to adopt a 'market driven' business strategy based on quality and customer service, rather than a 'technology led' strategy which uses technical specification and price to compete. To successfully implement this type of strategy there is a need for production systems to be redesigned to suit the new demands of marketing. Increased range and fast response require economy of scope rather than economy of scale while the organisation's culture must promote quality and process consciousness. This paper describes the 'Modular Assembly Cascade' concept which addresses these needs by applying the principles of flexible manufacturing (FMS) and just in time (JIT) to electronics assembly. A methodology for executing the concept is also outlined. This is called DRAMA (Design Routine for Adopting Modular Assembly).

Keywords:

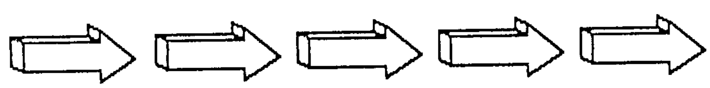
electronics assembly, high variety assembly, flexible assembly systems, process design methodology, implementation of new technology.

INTRODUCTION

The Emergence Of Market Driven Strategies In Electronics Production

A particular feature of electronics production in recent years has been the tendency for the industry to be increasingly dominated by large multinational corporations and conglomerates originating in Japan and the newly industrialised countries (NICs). The relative size of these organisations enables them to absorb the development costs of sophisticated high performance products which can then be manufactured in volumes large enough to derive the benefit of economies of scale. As a result, smaller indigenous firms now find it virtually impossible to compete on the basis of technical specification and price so, increasingly, the solution for many of them has been to become 'market driven' (ie providing solutions) rather than being 'technology led' (ie selling boxes). Electronics manufacturers that are technology led tend to focus their attention on 'upstream' (front end) operations. Here the output is mainly high volume, high value added items and the emphasis is on developing product innovations to improve performance and reduce production costs. Examples to illustrate this point include the development of smaller and more powerful semiconductors, the use of surface mount technology in printed circuit board design and fibre optics for data transmission. The way in which an electronics manufacturer can become more market driven is by focussing on 'downstream' operations where components and sub assemblies are brought together and configured to suit customer requirements. Here the material costs tend to be higher due to a larger 'bought-in' element of the products being made so, as a consequence, added value is reduced. Product varieties are also relatively higher, volumes lower and the point of production is much closer to the customer, which then places greater emphasis on service and quality. This in turn demands greater responsiveness and flexibility from the production system and a culture which promotes an orientation towards product and process quality, Figure 1.

Figure 1. The Features of Upstream and Downstream Operations in Electronics Production



Upstream electronics production	Downstream electronics production
(Front end items)	(Finished products)
* High volume	* High variety
* High value added	* High material cost (low value added)
* Technology led	* Market driven

The Role Of Customer Service And Quality

Greater responsiveness and flexibility are both characteristics of customer service; so to is the variety of products being offered. However, to provide good response and to be flexible while keeping inventories to a minimum is not easy and has been a problem for organisations of all types. 'Just in time' (JIT) techniques, originally developed by Toyota, provide a solution to this problem, Proud (1986). They keep down inventories by **pulling** materials through the production system in quantities only needed for immediate use, rather than **pushing** them through in larger batch quantities determined by a forecast of future requirements to which a safety factor has been added. The JIT approach obviously becomes more important as inventory holding costs and the material content of products increases. In electronics manufacturing both are significant since storage is expensive due to the nature of the materials involved (ie fragile printed circuit boards, delicate components etc) while in downstream operations materials can often represent more than 95% of production costs for finished goods. For these reasons JIT techniques are an attractive proposition in electronics production. However, the concept would seem to be at variance with the needs of high variety, low volume manufacture since normally it is assumed that large stocks of alternative components and materials are required to produce a wide range of variants. The second feature of market driven electronics manufacture, namely product quality, again requires a totally new approach to be taken. This involves a move away from the idea of 'quality of conformance', using control techniques which set down acceptable quality levels (AQLs) of one or two percent defectives. Instead, the emphasis is more towards 'quality of design' (both product and process design) using a total quality control or zero defects approach in which it is relevant to consider defect rates in terms of parts per million rather than parts per hundred. Again, however, this requires a change in culture on the part of more conventional organisations that are managed on purely functional lines and regard quality control as an independent activity divorced from production.

ADDRESSING FLEXIBILITY NEEDS

Flexible Manufacturing Systems

Responsiveness and product variety both demand greater flexibility from production systems and, technologically, this can be achieved using an FMS or 'flexible manufacturing system',Buzacott (1982). However, in most cases FMSs are limited to component processing where cells of numerically controlled metalworking machines are linked by automated material handling devices, the whole system being under computer control, Gilbert and Winter (1986). By contrast, the development of flexible systems for assembly is less well advanced. Conventional assembly lines can be reconfigured to create a 'multi' or 'mixed' model line, Wild (1984), but such an approach has considerable drawbacks. For instance multi model lines require periodic resetting and stocks must be generated to allow for periods when other models are being produced. In mixed model lines, on the other hand, the demand for each variant must be known and fixed in order that the line can be properly balanced. Moreover, even with the balancing problem solved, the line is often forced to operate at reduced efficiency levels to cope with the differences in work content associated with each design variant. Multi and mixed model lines can be appropriate in high volume, short cycle time, electronics assembly of the type used in 'upstream' operations. Here, for example, flexible automation can be used in conjunction with the insertion of components in printed circuit boards with assembly robots being reprogramed to suit each variant, Storjohann (1986). For final assembly of electronic devices, however, there are no cost effective automated systems which are both flexible and can handle major design changes in end products whose life cycles are inherently short, Kumpe and Bolwijn (1988).

Autonomous Working V FMS

An alternative method of enabling products to be assembled in greater varieties, which is not based on the use of flowlines, is the concept of 'autonomous working'. Here, individual operators or groups work in parallel at stationary work places (single-stage build) or follow products through self contained work areas which are linked to form a total production system (flow groups), Bennett (1986). Autonomous working is conceptually different from the idea of a conventional component processing FMS. It is based on the idea of moving away from the use of interdependent work stations arranged in a line towards the type of make complete production usually associated with jobbing or project systems. Conventional FMS on the other hand is based on applying computer numerical control to group technology cells rather than automating individual, functionally arranged, facilities. In group technology families of components are identified that are then produced in cells containing all the machines required to completely process them, Guerrero (1987). Batches can therefore be smaller than if functional layouts were used.

FLEXIBLE MANUFACTURING USING THE MODULAR ASSEMBLY CASCADE

Background To The Development of The Modular Assembly Cascade Concept

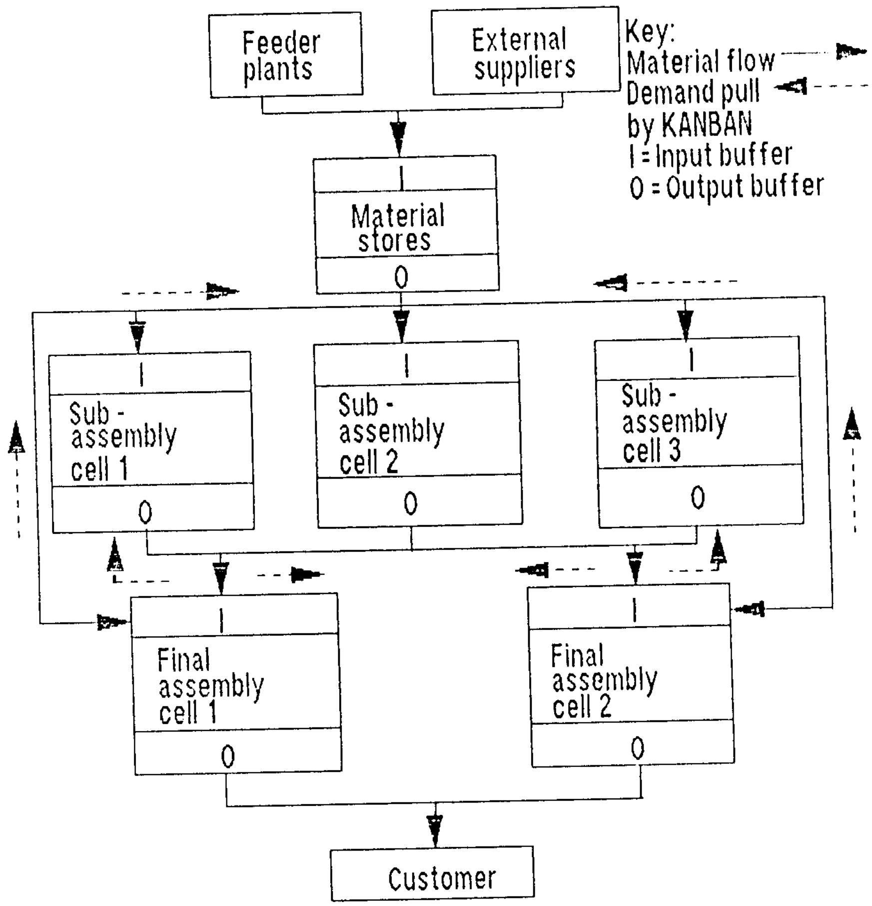
The idea of autonomous working suggests that its introduction is simply a question of job restructuring, and indeed many descriptions of the concept are devoted solely to the organisational and behavioural issues. In practice, however, physical system design to support flexible assembly using autonomous working is of paramount importance. Multi functional and sophisticated material handling systems are required that must be able to support a much wider range of tasks than is normal. A control system is also required that is capable of working in real time and can adapt to continually changing conditions. A concept that is designed to support this method of flexible assembly, which also allows the use of JIT principles is that of the 'Modular Assembly Cascade', developed in the UK by a major computer manufacturer. Despite being the Country's largest indigenous computer manufacturer this firm is in fact quite small by international standards, being only on fiftieth the size of its largest rival, yet it is still committed to compete in the fierce information technology market. During the early 1980s the

Company was in deep trouble. Sales were declining and, after seeing a succession of senior executives, was close to being put into receivership. Then a new management team took over that proceeded to totally change the Company's strategic direction. The marketing function was reorganised into 'business units' rather than being based on product types and a Company wide programme was initiated aimed at creating a customer orientated, quality conscious corporate culture. In 1983 the decision was made to introduce a new range of mainframe machines which could could be configured into around three hundred variants. This product, together with a recently introduced mini computer, would be assembled at a new plant which was opened in 1979. Despite being only a few years old when the new product was introduced, the plant still required to be equipped and reorganised to facilitate its manufacture. The reason for this was that the previous generation of machines was quite different in terms of their size and design and greater volumes and varieties of the new machine were also planned. Existing facilities and layouts were recognised as inappropriate given the new conditions so an ambitious programme was initiated aimed at completely reorganising the plant and replacing facilities with the overall aim of increasing flexibility. Being largely an assembly operation, with tasks being performed manually, most of the available FMS technology and hardware did not meet the needs of the Company so a unique approach was devised to suit its particular requirements.

The Modular Assembly Cascade In Practice

The Modular Assembly Cascade, as its name implies, comprises a number of modules within which various parts of the total assembly operation are conducted. They are largely autonomous, their main constraint being the overall dimensions of the products or subassemblies they can handle. Both between and within the modules JIT principles are applied. Modules manufacturing larger dimensional assemblies **pull** their requirements from those manufacturing smaller ones, hence the concept of materials 'cascading' down the various levels of assembly, Figure 2. The modules themselves derive their flexibility from making the production activities and material distribution system as 'generalised' as possible. This has meant re-equipping the assembly areas with more general purpose tools and investing in an ambitious programme of training to extend the range of operator skills and increase their ability to work in a less structured environment. Training in quality is also provided for all employees, both direct and indirect, and a zero defects programme is in operation coupled with the promotion of quality circles, Bennett and Rajput (1989). Automation of the assembly operations themselves is not feasible due to their complexity, the wide product variety and the lower volumes involved. However, it is used extensively for material handling and information processing. The type of equipment used here includes computer controlled cranes, automatic guided vehicles of various sizes and function, horizontal carousel and paternoster stores and automated testing facilities. A unique feature of the material control system is the 'electronic kanban' technique where the **pulling** mechanism of a 'kanban' card is replaced by the use of bar coded containers together with automatic data capture and transmission.

Figure 2. The Modular Assembly Cascade



<u>Implementing The Concepts</u>

Implementation of the Modular Assembly Cascade concept in the Company took place over a four year period between 1985 and 1989. The design and commissioning of individual modules took place incrementally, starting with a final assembly module having a one metre cube capacity, Nagarkar and Bennett (1988). Other modules include a two metre cube final assembly module and a number of sub assembly modules with differing size capacities. Kitting modules are located in the main stores where all the requirements for an assembly are checked and brought together according to a parts list produced by computer in response to the electronic kanban signal. The assembly modules also have their own input and output stores where 'strategic' buffers are located to provide product flexibility. In order to implement the total system a working party team approach was created comprising specialists from technical areas such as engineering and manufacturing systems as well as representatives from the functional areas affected by the changes. Incremental introduction of separate modules meant minimum disruption of other facilities while the continual learning process allowed future modules to be designed in the light of operating experience being gained. New control and performance measures were developed to be compatible with the service and quality needs of the system rather than just being based on the out of date idea of 'standard hour performance'.

THE METHODOLOGY FOR DESIGNING AND IMPLEMENTING MODULAR ASSEMBLY

The Need For A Methodology

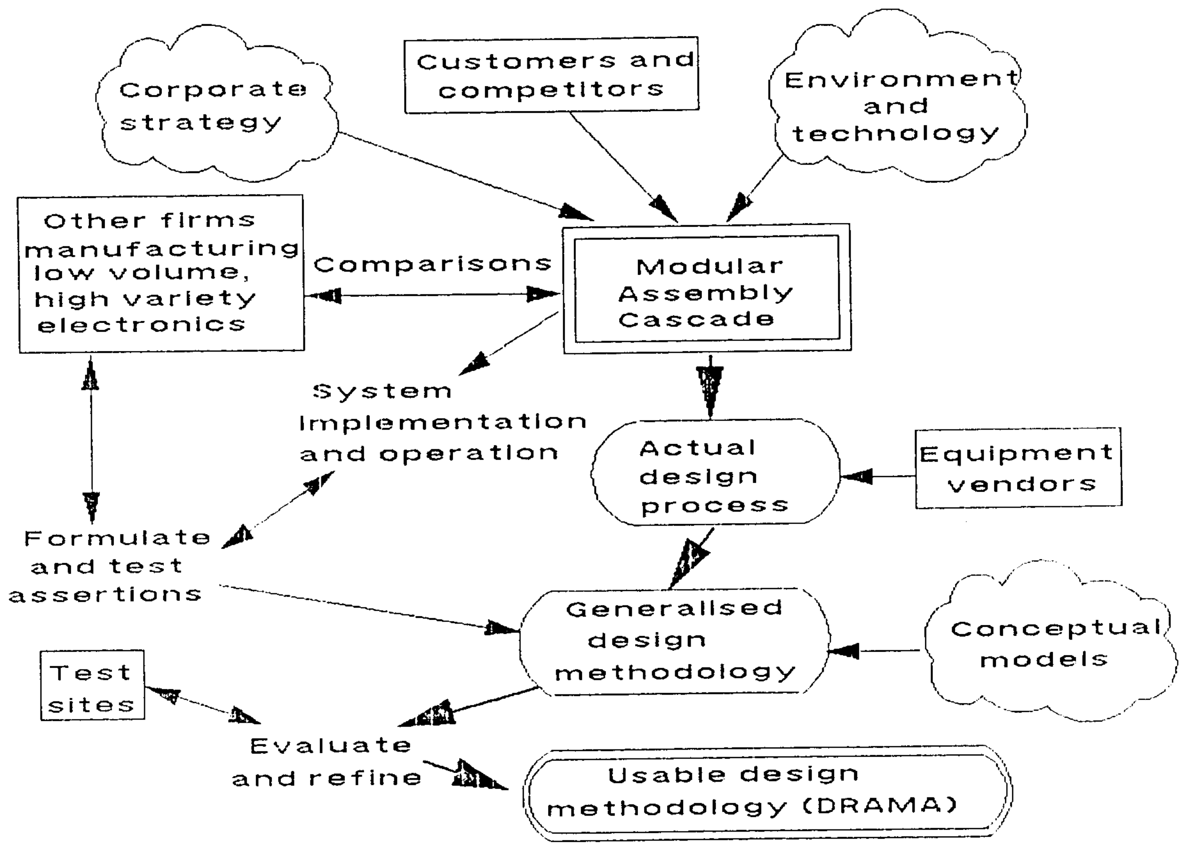
An important point to note about the Modular Assembly Cascade is that it should be viewed as a concept rather than as a fixed configuration of specific technologies. Therefore, other companies wishing to adopt the principle must appreciate that to copy the idea in a strictly physical sense will not necessarily provide the best solution for their particular needs. Instead, they should apply the concept via a methodology which guides the user through the decision sequences that must be followed in order to provide a solution to meet the requirements of the market and environment. The Innovation, Design and Operations Management Research Unit at the Aston University Business School has been producing such a methodology. Its development was made possible via a research programme funded by the UK Science and Engineering Research Council in collaboration with the originators of the Modular Assembly Cascade. The programme was of three years duration, employed two full time research staff, and was supervised by a team of three investigators from the University faculty. The research was centred around an in depth, longitudinal, study of the collaborating Company and was supplemented by a number of smaller studies in other companies. In order to observe the design process and and collect operational data the two research staff were absorbed into the Manufacturing Engineering Department of the Company, thereby being permitted much greater access than is common in industrial case study analysis. The main objectives of the research were:

1. To evaluate the effectiveness of cascaded FMS systems for high variety electronics assembly and test, from the point of view of engineering design and organisation.
2. To develop a methodology for cost effective design, development and implementation of generic FMS modules for assembly and test.
3. To evaluate the potential applicability of FMS modularisation within a variety of organisational, product and process contexts.

The Development Of The Methodology

The methodology is called DRAMA (Design Routine for Adopting Modular Assembly). It was developed by generalising and refining the design process for the Modular Assembly Cascade, Figure 3. The detailed study of the Company considered not only its customers and competitors, but also the environment in which the business was operating and the influence of corporate strategy on manufacturing. Comparisons were also made with similar companies manufacturing low volume, high variety electronics products. The process of system design in the collaborating Company was monitored and reconstructed using participative observation, an interview programme and documentary sources. Reference was also made to equipment vendors where relevant. In moving to the generalised methodology a list of underlying assertions was generated on which the Modular Assembly Cascade concept was based. These were then validated using reference points drawn from an evaluation of system implementation and the studies of comparable companies. Conceptual models were drawn upon, when appropriate, to assist with analysing the decision processes, Mintzberg et al (1976), and to provide a framework for the design routine, Roboam and Pun (1989).

Figure 3. Development of the Design Routine for Adopting Modular Assembly (DRAMA)



The Structure And Content Of DRAMA

DRAMA, Bennett et al (1989), comprises a number of components which together provide a set of guiding principles for organisations wishing to adopt the Modular Assembly Cascade concept, Figure 4. The methodology is, in itself, flexible in that it is based around a **philosophy** rather than offering a rigid prescription based solely on solutions devised in the specific case, Bennett, Rajput and Oakley (1989). DRAMA takes the form of a manual that is arranged in such a way that it is possible to choose different depths of use or to select only those components which are of immediate relevance to the user. The structure of the DRAMA manual, Figure 5, comprises a number of 'tracks' that can be followed either in parallel or in succession. The top level track is the case, documented according to the DRAMA categories. This is also arranged into the **strategic**, **tactical** and **operational** domains. Market and environment, manufacturing strategy, organisation and evaluation are strategic domain components. Those that fall into the tactical domain are organisation, justification, project management and evaluation. The operational domain includes project management, physical system design, control and integration, work design, implementation and evaluation. It is possible for the user to make separate reference to each domain if they wish or follow the track through its full sequence. The second track is an assessment of each case component based on reference to theory, comparisons with other plants and the performance review of the collaborating Company's implemented system. The final track represents the generalised process design methodology. Key parameters are firstly defined, then previously established relationships are used to determine the appropriate design variables. From here the user is guided through to a recommended generalised approach to modular assembly cascade design. Where appropriate the methodology employs narrative, decision trees, flowcharts, checklists and various decision aids. The sections of the manual are integrated via the 'front' sections which are (i) the introduction (ii) a description of the overall structure, and (iii) an explanation of the decision processes and information system concepts that will often span a number of the categories.

Figure 4. The Components of DRAMA

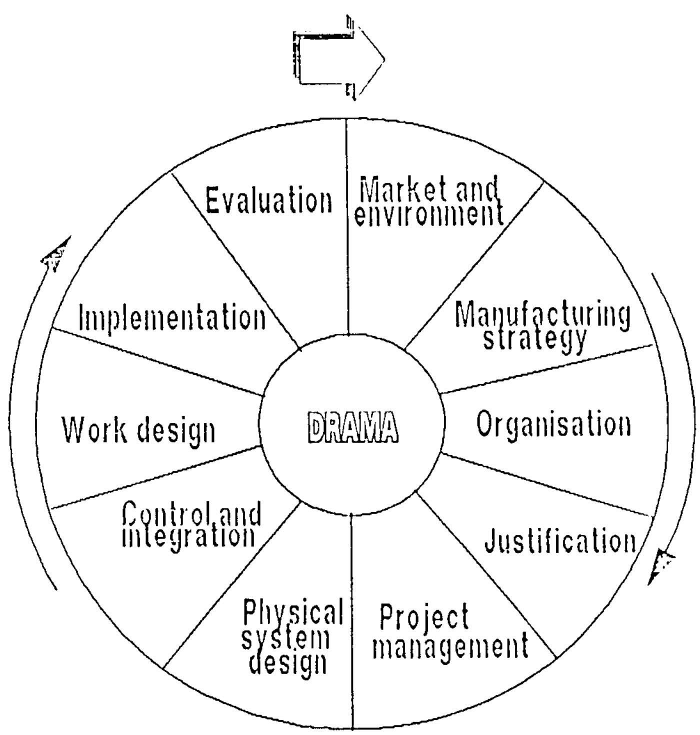
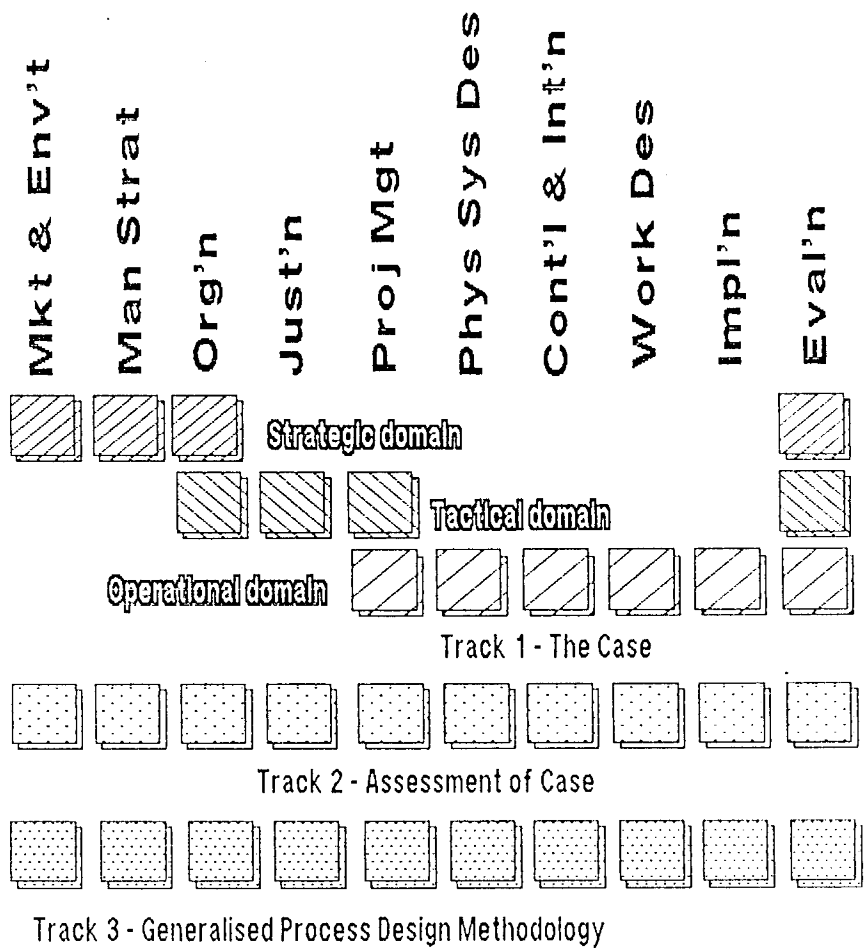


Figure 5. The Structure of the DRAMA Manual



CONCLUSION

The DRAMA methodology provides a useful means of assisting companies to adopt the concept of the Modular Assembly Cascade. It is not a rigid prescriptive model but allows users to define their own solutions via the guidance that is offered through a documented case. Its assessment and the subsequent, generalised, design recommendations based on defined key parameters provide a means of arriving at designs which tailor the Modular Assembly Cascade to particular sets of circumstances. The methodology is unique in that it is based on a live case that has been monitored and analysed in considerable detail over an extended period of time. Compared with 'snapshot' data collection techniques that are often used for this type of research the 'long term participative approach' has considerable advantages. For example it provides a greater 'richness' of material than could be gathered using conventional data collection techniques or even passive observation. It also enables the wide range of experience and knowledge that exists within the organisation to be captured by the freedom of access allowed. Furthermore, the natural interaction between research staff and Company employees allows a greater exchange of the views and comment necessary to refine the material into its final form. It must be recognised that the methodology developed, being largely based on a specific case, may have more limited generic applicability than one which is based on a wider source of data. However, the greater quality of data will make the methodology more robust. DRAMA is currently being tested in a number of situations to ascertain its applicability both within and outside its limits as suggested by the case. The outcome of this exercise will determine the future direction to be taken in developing the methodology further.

ACKNOWLEDGEMENTS

The opportunity to conduct the research was made possible by the UK Science and Engineering Research Council, that funded the project through its ACME (Application of Computers to Manufacturing Engineering) Directorate. The author would also like to acknowledge the contributions made by the two Research Officers, Dr Sushil Rajput and Mr Paul Forrester as well as the project's co-investigators, Dr Mark Oakley and Dr John Hassard (University of Keele).

REFERENCES

Bennett, D.J. (1986) Production Systems Design, Oxford (UK), Philip Allan.

Bennett, D.J., Forrester, P.L., Hassard, J.S. and Rajput, S.K. (1989) "A Model for Analysing the Design and Implementation of New Production Systems", Proc. 10th International Conference on Production Research, Nottingham (UK), August.

Bennett, D.J. and Rajput, S.K. (1989) "Design and Implementation of Production Systems for High Variety Electronics Assembly", International Journal of Operations and Production Management, vol. 9, no. 5.

Bennett, D.J., Rajput, S.K. and Oakley, M.H. (1989) "Modular Systems Integration for Flexible Manufacturing - The Case of Low Volume, High Variety Assembly", Proc. SAMT '89 Conference, Sunderland (UK), March.

Buzacott, J.A. (1982) "The Fundamental Principles of Flexibility in Manufacturing", Proc. First International Conference on Flexible Manufacturing Systems, pp. 13-22.

Gilbert, J.P. and Winter, P.J. (1986) "Flexible Manufacturing Systems: Technology and Advantages", Production and Inventory Management, vol. 27, no. 4, pp. 53-59.

Guerrero, H.A. (1987) "Group Technology: The Essential Concepts", Production and Inventory Management, vol. 28, no. 1, pp. 62-70.

Kumpe, T. and Bolwijn, P.T. (1988) "Manufacturing: The New Case for Vertical Integration", Harvard Business Review, vol. 88, no. 2, pp 75-81.

Mintzberg, H., Raisinghani, D. and Theoret, A. (1976) The Structure of 'Unstructured' Decision Processes", Administrative Science Quarterly, vol. 21, pp. 246-275.

Nagarkar, C.V. and Bennett, D.J. (1988) "Flexible Manufacturing System Lets Small Manufacturer of Mainframes Compete With Giants", Industrial Engineering, vol. 20, no. 11, pp. 42-46.

Proud, J.F. (1986) "Just in Time Manufacturing - A Winning Formula for Success", in JIT: An Executive Briefing, Edited by Mortimer, J., Bedford (UK), IFS Publications.

Roboam, M. and Pun, L. (1989) "Utility of Design Methodology for Advanced Manufacturing Systems", Computer-Integrated Manufacturing Systems, vol. 2, no. 1.

Storjohann, J. (1986) "Reducing Labor Costs Using Robotics in Electronic Assembly Manufacturing Operations", Industrial Engineering, vol. 18, no. 1.

Wild, R. (1984) "The Design and Scheduling of Flow Processing Systems", Chapter 15 in Production and Operations Management, London (UK), Holt, Rinehart and Winston.

BIOGRAPHICAL NOTE

David Bennett is Senior Lecturer and Head of the Operations Management Group at the Aston Business School, Birmingham, UK. He is also a member of the "Innovation Design and Operations Management" Research Unit. He has MSc and PhD degrees from the University of Birmingham, is a chartered engineer and member of the British Institute of Management.