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REFLECTIONS ON PRODUCTION PLANNING AND CONTROL (PPC)

Invited Paper

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Abstract

The paper examines the current state of Production Planning and Control (PPC), identifies some technical and systems changes that have occurred over recent years and links these with the requirements being placed on companies by the market. PPC is being asked to respond effectively to these internal and external changes by being more dynamic and providing better control of resources and delivery performance. Some of the requirements to be satisfied by the new PPC systems are identified. To meet these requirements it is suggested that better understanding is required of how different factors affect PPC systems performance and that administrative systems need improving. The quantitative, administrative and behavioural aspects of PPC are discussed. A framework for developing an agenda for action and research is provided.

Key words: production planning, production control, overview.

1. Introduction

Many technical and systems changes have occurred in manufacturing industry over recent years. The requirements being placed on companies by the market are also changing. Production Planning and Control (PPC) is being asked to respond effectively to these internal and external changes by providing a faster response and better control of resources and delivery performance.

The paper examines the current state of PPC.

The discussion then reviews recent developments in the market, manufacturing and manufacturing systems and relates these changes to our understanding of production planning and control. The description brings together many threads associated with PPC and identifies some areas where there are deficiencies in our understanding. Some thoughts are then presented on how PPC systems need to respond to the changing technology, changing market needs and individual customer's expectations.

All papers are personal in the sense that they reflect the interests and priorities of the authors. However personal opinions have deliberately been given greater weight in this paper than is conventional. Indeed, several sections of the paper contain ideas that have been partially tested but not fully evaluated. In that category are the personal classification and organisation of PPC described in section 4, the concurrent engineering views and figures in section 7, the framework for production management in section 8.1 and the tabular representation of actions in section 9. How the tabular representation leads to a possible research agenda also needs further evaluation.

The paper uses some general principles which, although not proven, have been reinforced over the years by personal experience and research investigations. Hopefully these principles will also be useful to you. They include:

- theory, simulation and practice should complement each other;
- systems integration is important;
- system commonality and structures are a useful basis for transferring experience;
- people are an integral and essential part of systems;
- automatic provision of data can greatly assist system maintenance;
- information is important;
- provision of PPC systems or information systems should be based on a proper economic assessment.

The conjectural nature of some aspects of the paper has been highlighted to encourage readers to be critical of the content and to ask whether the interpretations are consistent with readers' experiences. Feedback on whether the generalisations stand up to international scrutiny and apply to different systems will be useful.

2. What is PPC?

Companies wish to satisfy market demands expressed in terms of real or forecast demand. To do this companies in general produce a Master Production Schedule (MPS) that states the number of each product to be made over some planning horizon and a Sales Programme that states the number of each product to be sold. The PPC function and its associated systems aim to plan and control production so that a company meets the production requirements as effectively as possible. PPC systems are hierarchical. A hierarchical planning process is used for PPC to help a manager understand and control the operations for which he is responsible. A high-level plan sets the context within which the next lower level plans operate. The different levels in the hierarchy operate on different time scales. Typically aggregate planning is associated with long planning horizons and detailed planning is associated with short planning horizons. A common operational starting point for planning production is the Master Production Schedule from which the requirements of materials, parts, machines and labour are derived. Modifications may be made to the plans if the derived requirements are thought to be inappropriate. The consequences of the chosen plans, usually expressed as a list of requirements of made-in and bought-out parts, become the basis of the work schedules placed on individual men and machines and orders placed on suppliers.

The prime objective of production planning and control is to ensure that parts and products are produced so as to achieve the Master Production Schedule (MPS) in a way that is consistent with meeting the company's other performance measures. The MPS states the number of each product to be produced period by period over some time into the future known as the planning horizon. The MPS, in conjunction with the sales programme, is the company's planned response to the demands of the market. In particular, the MPS, company production and inventory policies and knowledge of inventory levels, are used to determine the number of items to produce, the planned inventories of raw material, work-in-progress, finished parts and finished products and the manufacturing resource requirements such as machines and labour. Plans should be realistic and avoid asking for the impossible.

The British Standards document BS 5192 Part 1:1993 states that the Production Control function comprises three inter-related stages: programming, ordering and dispatching. It also states that production control occupies a central position in the exchange of information between the functional departments within a manufacturing organisation. In particular it then goes on to mention the following seven groups of functions: sales/marketing, design/development, purchasing, finance/accounting, manufacturing/quality assurance/production engineering, distribution, personnel. A common representation of PPC includes the following characteristics:

- A hierarchy of planning that involves a progressive detailing of high level plans to produce operational plans and associated instructions;
- Communication that allows the plans to reach the appropriate people at an appropriate time and
- Feedback that provides suitably summarised information about performance to the controllers of the plans.

BS 5192 also makes the points that 'there is a tendency when designing production control systems to make them over-complicated.' and that 'In many situations there is an alternative to developing ever more complex systems to deal with increasingly complex operations. It involves putting effort into reducing or even eliminating the elements of complexity and uncertainty inherent in manufacturing operations…' Factors mentioned include: design for ease of manufacture, improving factory layout, introducing improved production methods, improving quality, etc. Some of these are discussed later.

3. The Current State of Practical PPC

PPC systems consist of inputs, transformations, outputs and appropriate control systems. Traditionally it has been difficult to plan and control production because of limitations in the planning methods and because unplanned changes occur in demand, supply and resources. In recent years further complexity has arisen because the emphasis of PPC has shifted from controlling individual plants to co-ordinating the complete supply and delivery chains. The production units may therefore be geographically dispersed and the systems in the different units, which are not necessarily part of the same company, may not integrate easily with the others. The consequence is that many companies find it difficult to provide the service required by the market. They also find it difficult to produce items according to their plans despite major developments in computer aided production planning and control and better systems understanding. Difficulties of planning and control arise when there is a mismatch or incompatibility between various parts of the total system i.e. any of the following:

- The input (the demand);
- The desired or chosen output (the Master Production Schedule and its implications in terms of production plans and plans for the supply of parts and material);
- The chosen production plans;
- The supply system that should ensure that suppliers deliver the correct quantities of assemblies, parts and materials of appropriate quality on time;
- The conversion process i.e. the production system and how well it performs;

- The control of the conversion process (how deviations from the production plans, system performance, forecasting system and supply system are dealt with).

There is frequently a gap between the theory and practice of PPC. Academics try to improve understanding of PPC systems by analysing the mutual impact of influential PPC factors whereas practitioners try to obtain usable results from a mix of non-ideal software and *ad hoc* manual systems. Practitioners often believe that academics are not investigating the 'right' problems and are touched by the arrogance of ignorance whereas academics are frequently unhappy about the apparent lack of understanding that production control managers have of straightforward concepts. As an illustration, practitioners need to agree lead-times at the time of accepting orders so as to be able to quote dates for delivery and to co-ordinate the availability of parts for assembly. Selecting a delivery date is usually achieved by assuming that the lead-time is fixed and deterministic. This may be a reasonable approximation provided that the load on resources stays fairly constant or fairly light. However, queuing theory clearly demonstrates that highly loaded resources, in the presence of demand and service both subject to variability, create long and variable delays. Actual lead-times are thus a consequence of the load on the system together with random effects arising from problems of quality, reliability of the machines and processes, deliveries, people and the demand. Rather obviously the quoted lead times affect the load, the level of stock and the probability of delivering on time. However, companies frequently adopt simultaneously the contradictory strategies of varying load while fixing the quoted lead-time. This may be one reason why many plans are unrealistic.

There are many systems of production control. In general, PPC systems have originated within industry although the major system software producers now have a great influence on their detailed content. Although some companies have local objectives such as keeping groups of individual men and machines busy, formal descriptions of PPC systems usually subdivide them into make-to-order and make-for-stock systems. Make-to-order systems, of which jobbing production is the purest manifestation, respond directly to customer's demands. On the other hand, make-for-stock systems, including base stock, re-order cycle (ROC) and sometimes re-order point (ROP) systems, attempt to bring stock up to pre-defined levels. Many systems, of which MRP is one, are a combination of make-to-order and make-for-stock. In MRP, customers' orders are accepted within the constraints of the Master Production Schedule (MPS). Conversely the MPS is chosen so that orders that have already been accepted will be produced. Of recent years, Just-in-time (JIT), which according to APICS (1998), is usually considered to be a philosophy based on the 'planned elimination of all waste and continuous improvement of productivity', has become fashionable and sufficiently important to become an objective of many companies. JIT is usually a make-for-stock base stock system suitable for repetitive manufacturing, but it has two features: demand pull and the minimisation of stock that together allow the system to respond effectively to customer orders. JIT frequently operates within the context of requirements derived by an MRP system. JIT has had some important successes but it has not been universally successful. Indeed the effectiveness of JIT systems has frequently been somewhat different from that expected even in companies that have claimed success in its implementation e.g. see WHYBARK (1996) and VASTAG & WHYBARK (1993).

MRP is still the most used production planning and control system. Over the last twenty years the procedures of MRP have been extended and developed to create Capacity Requirements Planning (CRP), Distribution Requirements Planning (DRP), Manufacturing Resource Planning (MRP II), Enterprise Resource Planning (ERP), etc. However, the basic system embedded within these extensions, is still MRP, an approach that has been heavily criticised partly because its centralised nature requires a large amount of data handling and the need to maintain highly accurate stock records. Nevertheless, it is essential for companies to co-ordinate deliveries and a wide range of other activities and so MRP has continued to be used even though the data handling may preclude responsiveness. The choice of parameters available within an MRP system and the differences between companies and their markets mean that it is unlikely that any two MRP systems are identical even if the companies use the same software. JIT and kanban systems also have great variety in the way that they have been implemented. In practice the same label, whether MRP or JIT, may be used to describe systems with different structures, different parameter values and very different performance. More confusing, but less frequently recognised, is that the labels, push and pull, that are commonly used to describe MRP and JIT systems are also defined in many different ways. Thus not only can different systems be described in the same way but the same systems may also be described in contradictory ways. This has been discussed in BONNEY *et al*. (1999a) and that same paper reports a simulation study that compares the performance of very simplified push and pull systems. The simulation indicates that under some specific conditions, push systems, appropriately defined, have similar potential for stock reduction as pull systems. The lack of precision with definitions has led to confusion within the literature and among production control practitioners. This suggests that to improve understanding it is essential to represent systems with clarity and desirable to represent them consistently.

PPC systems in companies frequently progress through a series of stages. In the early stages most company PPC systems are administrative systems built up *ad hoc* to deal with the housekeeping aspects of planning, ordering, receiving, issuing, making and storing items. Instructions are issued and transactions related to materials, men and machines are recorded. Unless resources are lightly loaded, it is common to find that order acceptance is not compatible with the resources available. This introduces uncertainty into the delivery times on top of the uncertainty that arises from changing customers' requirements, machine breakdowns, absenteeism, quality problems, etc. The consequence is likely to be a set of dissatisfied customers. To try to overcome these problems, procedures are introduced to perform actions such as master scheduling, lot sizing, setting safety stocks, rescheduling, setting time fences and extending planning horizons. Computer systems are introduced to handle the required data more effectively. While these methods help, they do not completely meet the needs of the companies and they frequently do not meet the needs of the users. Together the procedures used for planning and control make PPC systems surprisingly complex.

Since the earliest days of computerised production control, an objective of companies has been to develop Integrated Data Processing (IDP) systems. From the late 1950's to mid 1970's my personal experience in companies included linking financial and administrative systems with PPC, and linking CAD and PPC. In each case the systems formed the basis of a company wide Management Information System (MIS). In those early days bespoke PPC systems and modular packages both existed. TATE (1976) showed that the early modular packages were not as successful as bespoke systems. However, the use of packages has steadily increased so that the practice of MRP is now dominated by modular software. In recent years several big software houses have taken a major share of the market although there are still many smaller software/consultant companies implementing successful systems which apparently perform as well as the systems from the major players. With nearly every modular system, users are able to choose the modules and the sequence in which the modules are implemented into the company. The values of the parameters, used by the modules such as planning horizons, batch sizes, planned safety stock levels, smoothing constants, etc. are also chosen by the users. Of these it is likely that the time parameters (planning horizons, time buckets, time fences etc.) are the most critical. In many cases the values chosen are based on company convention rather than on an understanding of how these parameters affect overall performance. Probably because the potential gains that can be obtained from the use of 'good' PPC systems are not generally appreciated, the integration of the company's administrative systems is more likely to have a higher priority than the improvement of PPC performance. The criteria by which a PPC system should be judged e.g. delivery performance, quality expectations, cost, service, etc., are not fully agreed, perhaps because they are dependent on market expectations or competitors' actions.

Performance of PPC systems is improving in the sense that lead times are reducing and delivery performance is improving. However this has been achieved mainly by administrative means rather than by a clear understanding of the relationships between the variables. For example, as a result of using better data or performing simple arithmetic calculations, it may be obvious that there is a mismatch between different parts of the system e.g. the resources required and the resources available. If so, then action can be taken to increase or reduce the resources. In some cases, system performance may be improved easily e.g. by producing better demand forecasts, improving the master scheduling procedures or improving inventory recording. In other cases, the company may need to wait for an appropriate time to make the necessary investment e.g. in new machinery. There are frequently difficulties in meeting market demands within the constraints imposed by conventional investment appraisal criteria. However PRIMROSE (1991) suggests ways of appraising advanced manufacturing technology capital projects, including MRP, JIT and cell manufacture, by quantifying many of the 'intangibles'. It is particularly important that clear objectives are set when planning the system introduction so as to ensure that the expected gains are actually attained.

Surprisingly, many of the mistakes made in the early day of implementing computer systems still persist and the chosen implementation time scales are frequently optimistic. The most important requirement is that the top management is committed to the project and that appropriate preparatory work is done before going live. The preparatory work must ensure that staff are trained, appropriate data are available, the software is usable and that operational trials are undertaken. Whenever practicable the trials should include running the proposed and current systems in parallel.

4. Classification and Organisation of PPC

PPC systems can be classified, structured and organised in many ways. For the purposes of this paper, even though the categories are not independent, systems are somewhat unconventionally listed under the following headings: structure, mathematical modelling, data control, human centred systems and managerial style. Invariably advantage may be gained by simplifying the organisation and improving procedures. Items of this administrative nature are listed as a sixth category. These categories are now discussed.

System structure can be the basis of classifying PPC systems. Any structural representation needs to recognise that production planning and control is hierarchical and that different levels in the hierarchy operate over different planning horizons. Structures need to be consistent with developments in information technology and should also be able to represent the dynamics of PPC systems. The GRAI model (DOUMEIGNTS *et al.*, 1992) was developed primarily for systems analysis and design whereas the aim of the framework for production control (BONNEY & HEAD, 1993 and BONNEY *et al.*, 1999b) has been to increase understanding and assist the process of designing production planning and control systems. Some of the advantages of the framework and Petri-net modelling are discussed in Section 8.1. Petri-net modelling and control modelling, both useful representations for modelling the structure and the dynamic performance of PPC, are discussed respectively in Sections 8.1 and 8.2.

Representing systems by mathematical models allows the performance of a PPC system to be derived as a consequence of changing parameter values in the mathematical model. The approach is an effective way to improve understanding. In principle, if a mathematical representation was realistic enough it could be used to control the operation of the system. However, in practice there is a great deal of discretionary decision-making in the operation of systems involving people. In particular, differences in people's cognitive processes are hard to represent precisely. It is therefore unlikely that mathematical models will ever control complete plants except possibly in the process industries. In more traditional batch or jobbing manufacture, mathematics may be used to represent near deterministic situations e.g. to derive a master production schedule or to optimise some operational sub-parts of the problem. However, even problems with a classical structure e.g. sequencing operations on the shop floor, require close co-operation between the user and the algorithms to ensure that the discretionary needs of the users are not ignored. As system performance becomes more deterministic, the easier it becomes to represent mathematically and for its operation to become computer controlled. However, in most situations that prospect still looks a long way off because, in addition to the conditions not being sufficiently deterministic, many of the problems are still intractable.

Data control systems consider a system in terms of data and its flow between the different activities performed. The activities can be manual or computer based functions. They may be long standing activities performed by the company or they may have been recently introduced or proposed functions resulting from say a Business Process Re-engineering (BPR) exercise. Data control systems are straightforward to represent by IDEF diagrams. Emphasis on data control is often implicit within computer based control systems but there is a danger that an analyst will ignore the needs of some users and that some discretionary decisions will not be acknowledged. Such problems often come to light only when the new system becomes 'operational'.

Human centred or behavioural views of PPC systems are now recognised as important. Human centred systems emphasise the needs of the system users. Most studies of PPC take either a human centred view or a deterministic view, but means are needed to combine the deterministic and the human centred views. There are so many uncertainties in every production planning and control system that a human centred view is essential to allow the people responsible for controlling the flow of work to be able to contribute to the decision making. For example, as described by MACCARTHY *et al.* (1999), even in areas such as scheduling, a problem that is often expressed as a classical mathematical problem, human discretionary decision making is essential. People understand the current local difficulties whatever their cause. However, in order to contribute effectively, they will require appropriate information presented in a form that they can understand. Ideally they need an appreciation of causality and knowledge and experience of constructive methods of conflict resolution.

Systems based on managerial style are systems where the personality of the manager together with his cognitive style is a major component in getting the system to produce the results required. Direct managerial control is a natural and effective way to react to crisis conditions and operate in highly dynamic markets. Unfortunately this style of system operation often carries over to different conditions. Managers may continue to react to current crises and events even when these are the consequence of lack of planning rather than inherent conditions of the market. Resources may then be used inefficiently and ineffectively as the systems continue unnecessarily to be dominated by fire fighting activities. Obviously, the effectiveness of reacting rather than planning is dependent on the stability of the market conditions but, whatever the state, attempts to formalise the processes are a natural development. Anecdotally many personality driven systems that champion leadership ignore the needs of colleagues.

Organisational and procedural actions that simplify problem structure and improve performance can be associated with any or all of the above. They are the administrative changes discussed later. Typical changes that may simplify manufacturing control include:

- formalising procedures;
- having someone in charge;
- ensuring that data is accurate and up to date;
- changing factory layout to improve material flow;
- introducing product organisation and using cell manufacture and GT (Group Technology) for part manufacture and assembly, avoids many routing and control problems by requiring all items to follow the same sequence;
- using methods of continuous improvement;
- reducing unplanned activities and introducing lean manufacture methods e.g. by improving quality progressively to producing zero defects, improving reliability of machines, reducing the involvement of people by using robots to automate production, etc. avoids unnecessary disruption;
- introducing JIT pull systems that enable the company to respond directly to customers demand;
- sub-contracting or moving to a 'virtual enterprise' to avoid many of the internal control problems;
- working to a fixed programme despite fluctuations in the demand and working to a regular schedule means that everyone knows what is to be done without further instructions;
- having spare capacity as a contingency to reduce the need for formal scheduling;
- holding stock so as to provide a buffer against changes in demand.

5. Requirements Arising from Changes in the Market

Whenever and wherever companies innovate with products, processes, systems and marketing, that, in turn, imposes requirements on other companies to change e.g. to redesign products and shorten delivery lead-times. Low wage economies force industrialised nations to withdraw from the market, to sub-contract or to maintain their competitiveness by investing in productivity and in product and process innovation. The market wants low cost, high quality products available within a short delivery time. Companies wish to have high productivity, short manufacturing lead-times and to minimise stocks. They also need flexibility so as to be able to respond easily to changing requirements. Environmental, health and safety and product liability legislation impose other requirements on the organisation e.g. the need to be able to trace parts within a product. Environmental factors add the need to reduce the amount of packaging, to design for disassembly, to maximise the possibilities for recycling materials, to use more environmentally friendly materials and processes and so reduce pollution and energy expenditure, etc. The need to be able to maintain products in locations determined by the customer adds another dimension to design. There is also increasing concern about social issues such as the effects of shift work, the distribution of tasks between workers, designing jobs and workplaces to meet the needs of specific populations including different ethnic backgrounds, disabled workers, different sexes and different age distributions. Many other examples of changes, legislative constraints and the effects of globalisation could be added. In particular many problems are compounded by changes in the relative power of companies arising from mergers and take-overs and the changing values of currencies.

6. Requirements Arising from Changes in Manufacturing and Manufacturing Systems

Manufacture is responding to the needs of the market in a variety of ways. The responses include changes to the design process, changes to hardware, production methods and production support, changes that provide data more quickly and of better quality, organisational changes, changes to planning and control methods, etc. All of these changes need to be assimilated and integrated so that the total system remains a coherent integrated whole. One way to achieve this is to construct the system from a flexible set of customised modules attached to a software platform. In principle an appropriate software platform should allow systems to be changed quickly and without much disruption. The listed categories are not mutually exclusive in their effects e.g. different planning and control methods can improve the quality of data. Conversely providing data more quickly or of better quality may allow production planning and control to be improved. Some examples within each category of change are:

- Changes that may improve the design process and shorten the design time. These include:
  - Using computer-aided design (CAD) and computer-aided process planning (CAPP) to improve the consistency and flexibility of the design process, to reduce the design lead-time and to make design modification procedures more straightforward;
  - Using rapid prototyping to reduce the time to produce prototypes;
  - Designing for ease of manufacture (DFM and DFA);
  - Using modular assemblies so as to reduce variety in the organisation, make costing more secure and reduce the time and cost of production;
  - Using concurrent engineering to perform design and process planning, manufacturing systems design and PPC system design in parallel. This is discussed in greater detail in Section 7.

- Changes to hardware, production methods and production support. These include:
  - Using different processes, more reliable and faster conventional machines;
  - Using automatic methods to make individual components and assemblies more quickly, reliably and flexibly;
  - Implementing Computer Aided Manufacture (CAM) including CNC, DNC, machining centres and robotics;
  - Using cell manufacture;
  - Using conveyors and storage systems to provide better material flow and control;
  - Using different external transport to speed up receipts from suppliers and deliveries to customers.

- Changes that provide better quality data more quickly. These include:
  - Using computers to store and process data.
  - Implementing CAD to design products and to provide and maintain the bills of materials and the associated product structures data that will also be used by the PPC system;
  - Implementing CAPP to determine the processes to be used and the time they will take;
  - Implementing computer aided work-study to determine the methods and times required to make a product using manual methods. This is the equivalent to CAPP for manual work and so in principle it is now possible to provide the planned operation times for all work before the work starts;
  - Using bar code readers and sensors to collect data more quickly and reliably. Bar

coding may be used as the basis for collecting data that describes the current status (quantity, quality, location, stage of production or test etc.) of all aspects of the production system. The data can relate to material, parts, products, deliveries, returns, etc. and also to operators, machines etc. A separate decision is needed to determine whether collecting this data is economically desirable;
  - Using e-commerce to speed up the ordering and delivery process.

- Changes to the organisation of manufacturing systems. The company changes could include:
  - Changing objectives, goals and strategy arising as a result of management changes and reviews;
  - Using more focussed, flatter management structures and reduced vertical integration;
  - Extending control to the supply chain;
  - Making organisational and procedural changes to simplify problems as discussed in section 4.

- Changes to production and inventory planning and control techniques and tools. These include:
  - Improving master scheduling and its use;
  - Implementing computer aided production management (CAPM) software such as material requirements planning (MRP) and using better scheduling methods. This can help to plan and control production;
  - Using simulation to investigate many aspects of the production system before the work starts and to investigate the consequences of a proposed production programme and its detailed schedules.

7. Consequential Production Planning and Control Needs

Production planning and control technology needs to change from a craft process into a properly engineered process where the consequences of changing system parameters are clearly understood. When change was relatively slow, experience was a reasonable basis for action. However in times of rapid change, conceptual understanding becomes progressively more important and trial and error, which is the basis of experience, is too slow and risky. Better conceptual understanding and improved operational performance of PPC is particularly important because it drives much of the rest of the organisation.

Companies need to plan and co-ordinate all functional stages related to introducing a product from the initial product design, through production, distribution and sales and after sales service to scrapping and possible recycling. They also need to choose and create the associated systems that enable the stages to be planned, co-ordinated and controlled. There is a need to provide better responsiveness to the external changes discussed in Section 5 including competitors' actions and changing market demand. This means that companies should be able to reduce or increase production levels without ceasing to be profitable, to change models to meet new perceived needs, to change systems without excessive consequential costs, etc. It is desirable to reduce lead times while maintaining or even improving service levels. This requires a better understanding of the consequences of choosing specific values of the parameters such as safety lead times, frequency of scheduling, effect of delays and inaccuracies of recording, etc. It probably needs the dedicated development of lean manufacturing methods (total quality, dedicated workforce, reliable and accurate machines, reduced set-ups and small batches). There is a need to develop better ways of evaluating investment in appropriate capacity. PPC also needs to respond to the changes described in section 6. The high rate of change that has been described suggests that there is a need for routine procedures that systematically adjust the system consisting of products, processes, manufacturing system design, manufacturing and PPC so that they remain in balance.

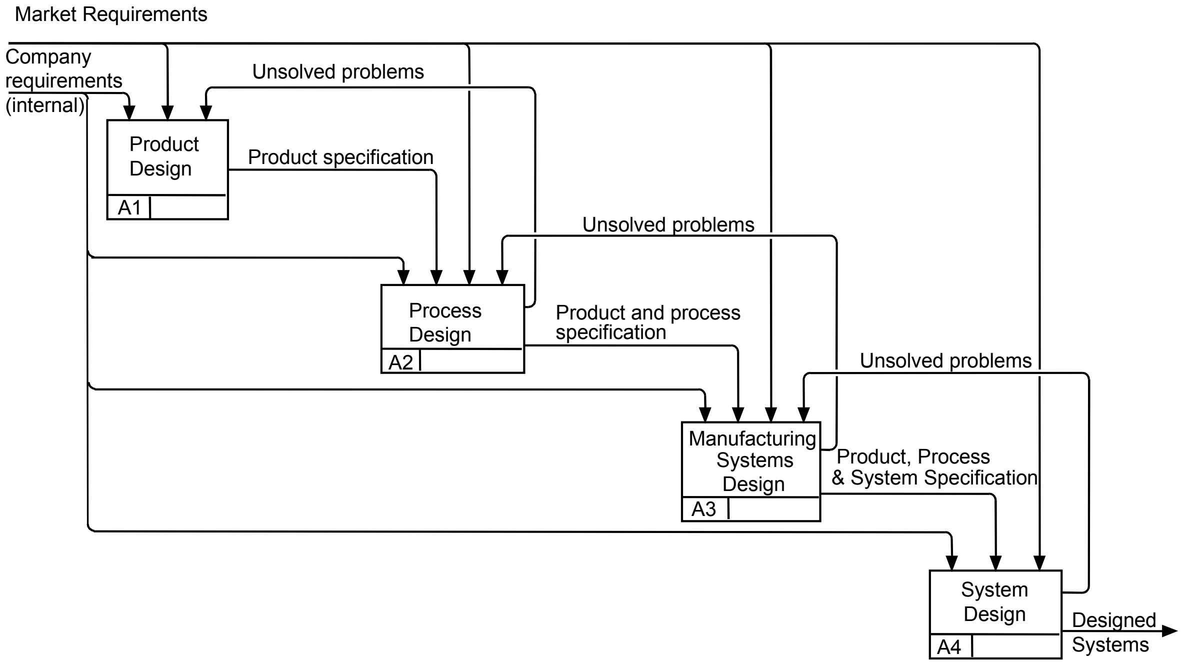

Figure 1 – A concurrent enterprise representation.

The paper has illustrated that manufacturing and logistics systems are complex, integrated and dynamic. Changes to any of the functions e.g. product design, process design or manufacturing systems design require adjustments elsewhere. A method of representing the dynamics of the inter-relationships between the different functions is important, as it will help to clarify the relationships. In BONNEY *et al.* (2000a), the product design, process design and manufacturing system design stages of introducing a product into production are represented in structured analysis format. The stages are kept in balance by the use of a hierarchical, iterative design process. Detail may be progressively added to each stage of the hierarchy but if the detailed consequences are unsatisfactory it is possible to return and modify the previous stage before adding further detail. The need to consider interactions between each stage makes design concurrency important. The representation proved to be very helpful and so the idea was extended to link product design, process design and manufacturing system design with the three parts of 'system design' namely: 'PPC system design', 'business system design' and 'external systems design' as shown on Figure 1. Applying these concurrency ideas to the whole organisation defines the concept of a 'concurrent enterprise'. Figure 1 is a structured representation that links product, process and manufacturing system design with 'system design'. Figure 2 is a more detailed representation of the process of determining the 'PPC system' part of 'system design'. Figure 3 represents the planning hierarchy of an MRP system, which is a possible output of the design process illustrated in Figures 1 and 2. These ideas were discussed in BONNEY *et al.* (2000b), which contained much of the information of sections 5 and 6 and also listed some of the major changes facing production organisations from the market and changing technology. It then presented in an almost random sequence a list of requirements being placed on production planning and control. These requirements have since been categorised and are discussed in detail later in this section under the headings general requirements, stock reduction requirements and quantitative, behavioural and administrative activities.

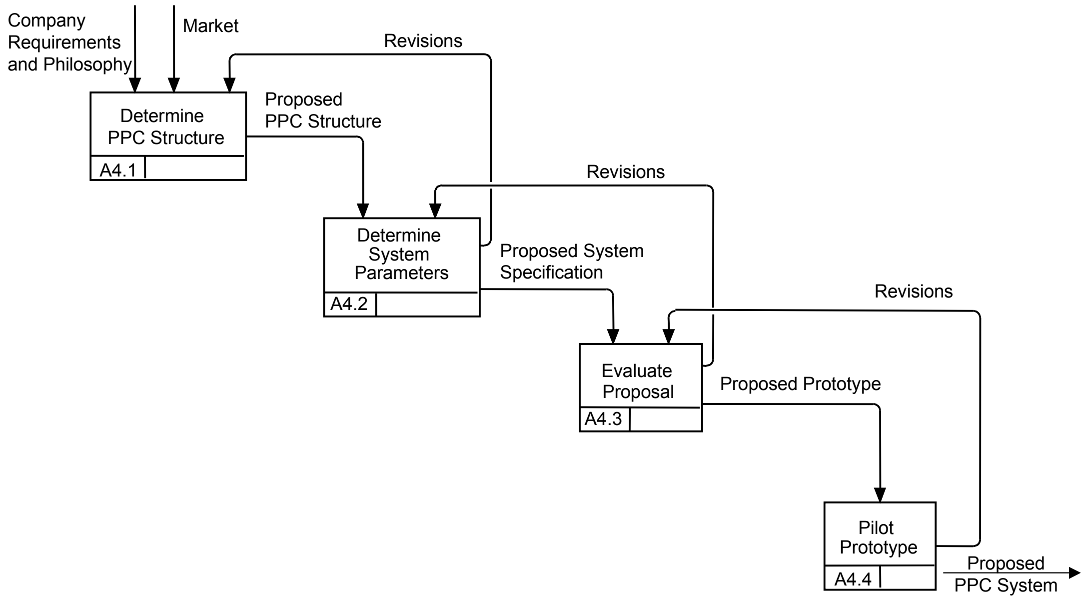

Figure 2 – Iterative design of the PPC system.

The general requirements being placed on PPC include the need to identify performance measures and to improve performance. The requirements include the need to improve schedule conformance, provide systems with greater flexibility and provide greater return on capital employed. Inventory planning requirements include the need to provide better service. This is usually interpreted as the need to shorten manufacture lead times, reduce work in progress and reduce stocks in the logistics chain but occasionally it may require relocating stocks and sometimes increasing stocks. A variety of methods may be used within a company including using lean production methods, using smaller batches and reducing safety stocks, managing inventories better by using appropriate inventory control systems that also provide accurate and up to date inventory records and associated control data. Together the items on this list help production and inventory planning and control to be more responsive. However the exact balance and sequence of implementation will vary from company to company.

Co-ordination of multi-level multi-product planning and control systems is particularly difficult. Many of the tools required now exist but there is still little experience in bringing them seamlessly together. Actions that improve performance can include formalising the administrative procedures, obtaining better understanding using quantitative studies and working better with people. Quantitatively the need is to investigate and model the relationships between the variables that affect the performance of PPC systems so as to be able to choose and then operate a PPC system that matches the variables and improves the performance of the company. So far researchers have given greater weight to quantitative studies based on mathematical analysis and simulation whereas companies have given greater weight to administrative changes. There has been insufficient investigation into improving understanding of human behaviour.

Behaviourally the need is to understand better the needs of the community that is the company. The people operating the system need to be involved. They also need to be provided with appropriate information so that they may use their local knowledge. The requirements for this are essentially what is called good management. Behavioural effectiveness is closely linked with the administrative needs discussed in the next paragraph. The actions required include:

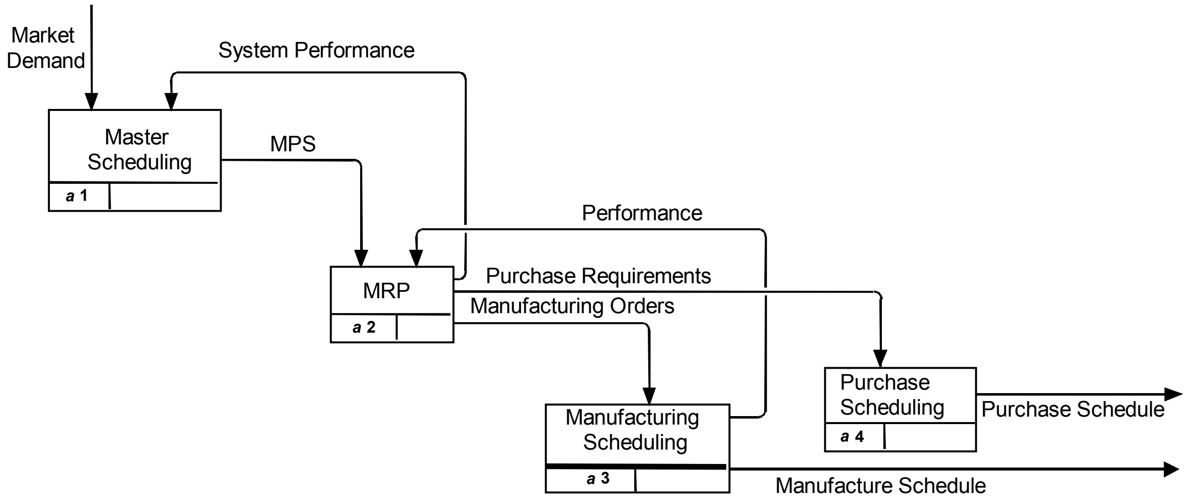

Figure 3 – A planning hierarchy for an MRP system.

- Educating people so that they know why things are being done;
- Training people so that they feel ownership of the system and can operate the proposed new system with confidence;
- Involving people and changing things in a way that motivates;
- Doing the things that are required e.g. for legislative reasons to meet Health and Safety requirements, employment law, etc. in addition to the actions needed to control production;
- Ensuring that the results are consistent with the needs and wishes of the people operating and affected by the PPC systems;
- Monitoring and modifying systems so that they are maintained and improved.

Administratively the aim is to produce good structures and systems that co-ordinate manufacturing across the extended enterprise logistics chain. In general, managers intuitively see the need to formalise systems, to control data better and to simplify systems. Providing realistic operational schedules with regard to lead times and capacity will reduce uncertainty and reduce the need for rescheduling. To operate a quantitatively based PPC system requires maintaining accurate, up-to-date records of basic data including product structures and the operations and the associated processes that are used to produce the parts and products. It also requires the maintenance of accurate and up to date stock records. Technically, it is now possible to collect data relating to all transactions virtually instantaneously. However, if all data were presented to a manager, the volume would make it impossible to look at let alone interpret. It is therefore essential to convert this raw data into information that is understandable and usable. This is a requirement of the management information system. Typically this is achieved by filtering and summarising the raw data and then presenting it, possibly in the form of exception reports e.g. items late, items outside predefined control limits, etc. Different levels of aggregation are likely to be appropriate to different levels of management. The information that is presented could conveniently be considered to be part of a decision support system (DSS). The information requires to be personalised to meet the needs of individuals, each of whom is different. Above all there is a need to provide each manager with information appropriate to his responsibilities. However information is also motivating and the consequences should be consistent with the performance measures and needs of the company. All of the above has to be done within the culture of the company. Specific steps include:

- Identifying the person responsible for each particular function and its component procedures. In particular the persons responsible for providing and maintaining data need to be identified;
- Defining the Human Computer Interface (HCI) for each function;
- Organising and formalising procedures for performing each function;
- Simplifying the PPC organisation and procedures.

Another need is to improve planning procedures. It is particularly important to address the issues of determining Master Schedules so that the performance can be potentially the best whatever the constraints. It is particularly difficult to plan and control small batch repetitive production of multi-level, multi-item complex products with variable demand and long lead times. Despite being unfashionable and having many features with which there has been much dissatisfaction, Material Requirements Planning (MRP), a practical method developed within industry, continues to be the method most frequently used for this purpose. As briefly discussed in Section 3, dissatisfaction with MRP arises from a number of causes that include inherent contradictions in the system related to lead times and capacity, the need to maintain highly accurate stock records and difficulties associated with rescheduling. Further, despite obvious links with design, process planning and shop scheduling, most companies require their planning and control systems to live with the consequences of changed product structures, obsolescence and configuration control rather than becoming part of the multi-variate decision process. Even investment in new machines and processes that affect capacity and manufacturing methods is usually decided independently of the planning procedures even though lead times and potential output will be affected. Therefore, there is a need to develop systems that examine the planning consequences of such proposed changes as part of the investment appraisal procedures. Despite these legitimate criticisms and weaknesses, the issues partially addressed by MRP have not gone away. A method with many of the features of MRP is essential to enable organisations to co-ordinate the availability of parts required for the assembly of complex products made on an intermittent basis. Production still needs to be planned and the activities still need co-ordinating. However, it is important that the methods used should be improved.

There is also a need to improve operational control on the shop floor so that the system can respond to changing operational conditions arising from the situation of uncertainty in the production environment and the market. One way to do this is to incorporate ideas from lean production, particularly those based on local visual control, into the manufacturing environments where MRP is currently used. For example, introducing local control into a push system offers the possibility of combining the organisational benefits of pull systems with the central planning and information system benefits of current systems. Another requirement is to introduce better shop scheduling.

8. Some Supporting Ideas

The aim is to produce a research agenda that satisfies the 'consequential Production Planning and Control needs' listed in Section 7. First some ideas that provide a basis for conceptualising some aspects of the proposed research agenda are discussed. They are 'a framework for production control' and 'control theory analysis'.

8.1 A Framework for Production Control

A framework for studying production planning and control was described in BONNEY & HEAD (1993) and BONNEY *et al*. (1999b). The framework may be represented schematically by Figure 4.

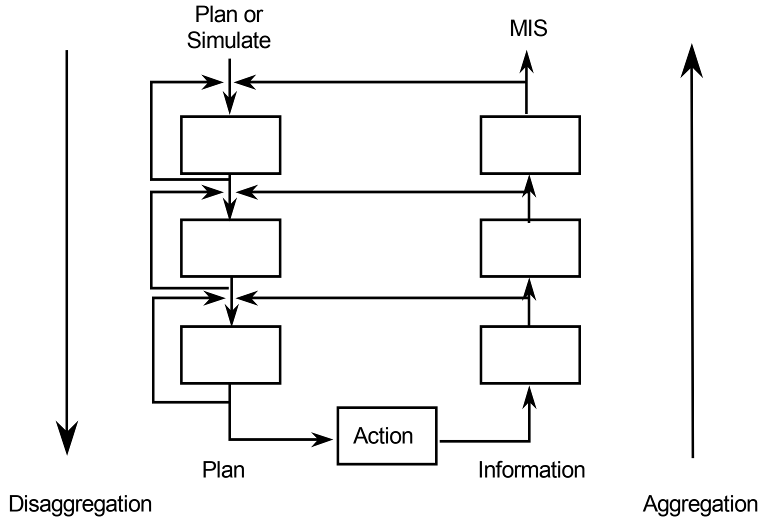

Figure 4 – A production planning and control framework.

The framework was proposed to represent the structural commonality of production control systems. The characteristics of the framework are a planning hierarchy, a hierarchy of simulations, a reporting or management information system hierarchy and a set of feedback loops. Theory, practice and simulation can be represented within this common structure. The planning hierarchy dis-aggregates high level plans into more detailed plans. For example, MRP converts a Master Production Schedule into the requirements for parts and materials needed to make the products while also taking account of performance against previous plans. These requirements may then be converted into schedules for purchasing and manufacture as shown in Figure 3 and it is on the basis of these schedules or plans that action is taken and the results recorded as transactions. The simulation hierarchy is part of the planning process and provides information on the likely performance of the plans. The management information system (MIS) hierarchy processes and aggregates the transaction data to produce performance reports. These performance reports are used as feedback information to indicate to the planning functions that plans should be modified or other remedial action taken if required.

The reasons for creating the framework were to:

- provide a way of examining PPC systems at the structural level;
- provide a method of classifying PPC systems;
- allow theory, simulation and practice to be represented in a common way and so allow the methods of one approach to be more easily appreciated and possibly used by another;
- provide a basis for allowing one system to evolve into another.

Each of the boxes in the schematic framework represents the transformation of specific inputs into specific outputs and each of the lines connecting the boxes is an information flow, the direction of which is shown by an arrow. The structure of the framework is consistent with the IDEF structured analysis representation, input-output models and control theory models. For example, in a control theory model the boxes shown in the left hand side of Figure 4 could be transfer functions representing the different parts of the planning system and the boxes in the right hand side could be transfer functions representing the processing performed by the information system. The level of detail that is included is chosen to correspond with how the framework is going to be used.

A framework model clarifies the relationships between the variables in production control systems, indicates possible omissions or deficiencies in a particular system and provides a way of describing an evolutionary path from one system to another. Potentially the parameters of the framework are the basis for a classification of production control. Important parameters include the number of levels in the hierarchy, the degree of parallelism in the system and the relation between the time based variables such as lead times, planning horizons, planning period and rescheduling frequency. The framework structure may be used to develop theoretical and simulation models. However, simply to make these assertions is unconvincing because the whole approach is abstract. There is a need to be able to illustrate and test the structure and show how it can be used. The UNISON software (BONNEY *et al.*, 1992) based on Petri-nets was created at the University of Nottingham to allow this to be done. The UNISON software allows one to simulate proposed structures. Hence the framework can represent dynamic systems and within these derive and evaluate the effects of changing values of the variables. Petri-nets are well described in several text books e.g. DICESARE *et al.* (1993) and PROTH *et al.* (1996). UNISON can represent the generalised framework and data converts this to represent a specific system structure. This representation can then be used to create a simulation model that can be used to predict the system performance in response to given inputs. If the performance of a specific structure is poor and there are structural omissions in the system representation compared with the generalised structure e.g. a feedback loop is not present, then the effect of 'correcting' the structure could be considered. The values of the parameters such as those mentioned above define a specific system structure. Changing the values of the parameters in the model of the generalised framework could thus represent a move from one system to another. If UNISON is used to represent the transition from one system to another this allows the system performance of each system to be assessed individually and during the transition.

Many systems have been represented using the framework and the associated UNISON software. These include the modelling of FMS, the use of the software as a tool for enterprise integration described in BONNEY *et al.* (1992), and a comparison of the performance of push and pull manufacturing systems described in BONNEY *et al.* (1999a). Another problem investigated was inventory planning in the context of enterprise integration described in BONNEY *et al.* (1996). The model that was used included the conversion of a master production schedule into a detailed shop schedule. Although managers in conjunction with software achieve this moderately successfully in most companies, it is surprisingly difficult to formalise the logical rules. Indeed there appears to have been little insightful analysis of the problem of ensuring that detailed plans are consistent with aggregate requirements. In principle this may be achieved by using mathematical programming methods but, in practice, the usual reason for detailing plans is to add further information often including the knowledge of the human planner. This is an example of the need for human involvement outlined in Section 4. Also working on a finer time scale introduces further constraints. Appreciating this practical difficulty was a direct consequence of taking a structural view of different control systems. Likewise it is difficult to ensure that equivalent bases are chosen when comparing the performance of different production control systems such as a kanban-based pull system and a repetitive batch push system.

8.2 Control Modelling

Transform methods have been used for analysing production and inventory control systems since the seminal work by SIMON (1952). These methods provide an understanding of the influence that variables have on system stability and system performance. Until recent years however the use of transform methods for studying PPC has been intermittent rather than systematic. Even now the methods are seldom used by industry as part of their PPC system design procedures. The next few paragraphs outline some results obtained by applying control theory to PPC.

If a block diagram representing a system can be drawn and the transforms and transfer functions are known, then an analysis can be performed. In particular, if the transfer functions that represent the boxes in the framework are known then we immediately have a model of the specific system in framework format. Popplewell used z-transform methods to analyse the response of re-order cycle systems and MRP systems to standard inputs such as an impulse, a step or a sinusoid. A generalised model of the different information flows of these two multi-product, multi-level planning and control systems was constructed and the system transfer functions derived. The stability and performance of these systems in response to different demand patterns was examined both analytically using z-transforms and by simulation. Some of these analyses were reported in POPPLEWELL & BONNEY (1987) and in BONNEY & POPPLEWELL (1989). Matoug subsequently extended this work to study the effect that misinformation, e.g. inaccurate stock records and the effect of delays in providing information to these systems, had on system performance. These studies were partially reported in BONNEY, POPPLEWELL & MATOUG (1994). Again the system transfer functions were derived and analyses made. Initially it was assumed that the data such as product structure information was available and correct, that stock levels were correct, that information was available instantly and everything behaved as planned including manufacturing lead times and the planned delivery policy. Then various imperfections were introduced e.g. to analyse the effect that misinformation and delays have on system performance within the re-order cycle and MRP systems. A particularly interesting result was the confirmation that high stock accuracy is essential if a MRP system is to perform effectively. Other studies examined how the number of levels in the product structures, determined during the process of design for manufacture, affect system performance.

For some years now, a group under the supervision of Grubbstrom at the Linkoping institute of technology in Sweden has been using Laplace transform methods, input-output analysis and net present value methods to study the performance of MRP. Laplace transforms are a general method for analysing linear control systems or linear differential equations. Laplace transforms include z-transforms as a subset. This work, a good summary of which can be found in GRUBBSTROM & TANG (2000) has extended the ideas to stochastic studies and discrete decision rules. This has considerably enhanced our understanding of the performance of MRP systems including the problem of backlogs. Other relevant studies using control theory are the use of modern control theory by O'Grady, who among other models developed a generalisation of the HMMS linear decision rule (HOLT *et al.*, 1960) applicable to multi-product, multi-period systems e.g. see O'GRADY & BONNEY (1985). TOWILL (1992a) reviewed control theory applications in manufacture and in TOWILL (1992b) described work at Cardiff that linked Industrial Dynamics type simulations with control system analyses. WIKNER (1994) describes work that links the Linkoping and Cardiff studies.

The importance of control modelling is that it has laid the basis for a deeper understanding of the reasons why PPC systems behave as they do. Converting this understanding into effective operational rules promises great improvement in the future performance of PPC systems.

9. An Outline of the Actions Required by PPC

Table 1 is used to illustrate the actions that should be taken by PPC to respond to the needs identified in Section 7. The rows show some of the major areas of concern e.g. Row 2 shows the 'General Requirements' suggested in

Section 7, namely that planning needs to be more frequent, that planning periods should be shorter and that there should be better dynamic response to changes. The columns of the matrix show the major steps involved. As an example, Row 1 is the overall task of introducing a product into production. The steps are product design, workplace design (called Manufacturing systems design in Section 7 and Figure 1), system design and then 'implement and operate'.

The individual cells in the table represent actions that should be taken or research that is needed. Investigating what to enter into each cell formalises the steps of the total system design in a way that is consistent with a concurrent engineering approach. When there is uncertainty about what actions to take, it will be difficult to define the cell entry and this should prompt an information search. When the information is non-existent or unsatisfactory, it points to the need for research. A finer division of the columns or cells may be used to provide a clearer focus. For example, sub-dividing the heading PPC System (part of system design) into aggregate planning, master scheduling and operational planning and control can help to clarify the PPC research problems. Then, the tasks of selecting the best aggregate plan, the best MPS, the best shop schedule and appropriate feedback are entered in Row 3 because they determine the appropriate stock levels. To identify the research requirements one could ask whether it is known how to choose the best solution even under restricted conditions. One could then extend the questioning to consider quantitative, behavioural and administrative headings. One could further consider whether a proposed solution would still match the requirements if all of the major steps were considered (the top row) and whether it would have knock on effects, possibly adverse, on items in the left-hand column. The steps involved in 'Introducing a product into production' row and the 'PPC system' columns are described in greater detail below to clarify the approach further. For some of these steps comments are shown in Italics that relate to Table 1 and to other relevant sections of the paper.

There could be large amounts of data linked into decision support systems with appropriate and possibly changing performance measures. There is a need for appropriate (hopefully reduced) stock levels and for systems to be more flexible and easier to reconfigure than at present. It is particularly important to understand how production parameters, particularly planning horizons, planning periods and planning frequency, affect PPC performance. This better understanding will improve confidence that planned actions will produce the required results. In addition to this formal (theoretical) understanding there is a need for these methods to be converted into tested operational rules and for the PPC staff to be sufficiently well educated and trained that they can operate comfortably and effectively with the new paradigms. Some of the DSS requirements have been summarised in rows 6, 7 and 8 of Table 1 labelled 'data source', 'data files' and 'filter aggregate and compare'. The implications of the matrix are still being actively considered.

Introducing a product into production *(Top Row)*

To understand the problems that arise when introducing a product, first choose a method e.g. structured analysis that can represent the steps of the product introduction process, then create the representation and then examine the implications of the representation. Some of these individual steps are now expressed in greater detail.

- Choose an appropriate representation for the major steps of the product introduction process. (*Top Row*)
- Represent the generalised product introduction process using a 'concurrent engineering' representation. The steps include design for function, design for manufacture, manufacturing system design, PPC system design and business system design. *(See Figures 1, 2 and 3 of section 7)*

Table 1 – Introducing a product into production. Some steps in system development, implementation and operation.

1	Introducing a product into production	Product Design		Workplace Design		System Design			Implement and Operate
		Design For Function	Design For manufacture	Facilities layout	Design Workstation	PPC System	Business System	External System	Plan implementation and Operation
2	General Requirements	Plan and co-ordinate all functional stages. Plan more frequently, shorten planning periods and improve dynamic response							
3	Reduce Stock levels	Use standard components and modular design. Reduce variety	Use standard components, modular design and GT	Use Pallets, Conveyors etc Organise by product or cell, etc	Standard workplaces	Choice of PPC & I C system	Choose performanc e measures	Link with Supply chain	Implement PPC &IC systems. Link with supply chain
4	Flexibility and responsiveness	Allow for extra features	Use standard components Select by lead time	Flexible layout	Flexible Workplace	Flexible planning	Appropriate costing	Link with Supply chain	Use modular system
5	Organisational requirements	Concurrent Engineering				Flexibility		Link with Supply chain	Matrix organisation?
6	DSS Data source	CAD system	CAPP	CAPL	CAWS	Plans and Transactions	Standard and actual costs		Inventory records Demand forecasts etc
7	DSS Data files	Store, update and present							Maintain and use
8	DSS Flexibility to filter, aggregate and compare	Design progress		Manufacturing system design performance		PPC performance	Performanc e and variances	Market information	Analyse performance e.g. surpluses, shortages, lateness, Pareto analysis etc.
9	Staff training and development	As required to meet new skills requirements							
10	Administrative actions	Ensure that the required actions are effectively and efficiently performed							
11	Quantitative Analysis	Achieve better understanding and select appropriate values of parameters							

- Use the representation to examine the implications of proposed products, process or manufacturing system design changes. (*Sections 5 and 6)*
- Develop a systems framework for incorporating theoretical developments into future systems. (*Figure 4)*
- Understand the effects of changing the system structure. *(Analysis of models based on Figure 4)*
- Understand the effects of changing the rest of the manufacturing system.
- Determine the response of a proposed system to changes in the market. *(Different inputs into Figure 4)*
- Determine the relevant system variables to study and determine how they influence system performance. *(Mathematical analysis, Sensitivity analysis and simulation)*
- Investigate the effect of structural features such as the number of levels in the hierarchy on manufacturing system performance. *(A detail of Figure 4)*
- Implement and operate the system.

'PPC system' design. *(This 'Design System' column is a detail of 'Introducing a product into production')*

- match a company's PPC system response to the products and the environment (technology and market) in which the company operates *(Sections 5, 6 and 7)*;
- determine the factors, including the range and complexity of the products and the variability of the market demands, that influence the choice of system;
- choose the levels of aggregation for planning;
- choose the values of time-based variables e.g. planning horizons, planning frequency and rescheduling frequency;
- check that the response is stable *(See section 8.2)*.

Investigate supply chain problems. *(This is the 'External System' column of 'Design System')*

- The supply chain may need to co-ordinate different organisations working with different planning periods such as days, weeks, 4 weeks and calendar months. More important is that the dynamics of the interactions and delays become more noticeable over the supply chain and minor fluctuations in demand may get greatly amplified. *(Analyse as in Section 8.2)*
- There will be shorter time to change models. The effects of introducing a new model spread throughout the chain and there are risks of obsolescence when the model stops.
- The financial implications of delays in payment and the cash in the supply chain and the costs of stock may be harder to identify particularly when there is rapid movement between organisations e.g. with JIT much of the stock may be in transit.
- Insights are needed into how E-commerce might enhance supply chain co-ordination and planning.

Determine and implement the operational system.

- evaluate methods for co-ordinating the availability of parts and tools for complex assembly work with demand;
- determine the implementation procedures;
- develop a prototype operational system representative of the next generation of systems for planning and controlling manufacture;
- implement the system;
- operate the system and maintain control;

Choose an appropriate Decision Support System to provide responsive planning and control.

- choose the levels of aggregation for reporting;
- choose performance measures;
- determine the level of discretion that should be given to individual managers;
- determine how to personalise information for users;
- introduce local control;
- use methods of visual control to improve load control and the operational performance,

controllability and flexibility of MRP-based installations;
- choose the MIS.

Possible topics to consider under the quantitative and administrative headings now follow. Additionally, and not discussed further, there is a need to implement and improve understanding of behavioural (Human-centred) systems e.g. scheduling.

Develop quantitative modelling to:
- understand the relation between variables that affect the performance of PPC systems;
- evaluate theoretical methods for planning and co-ordinating multi-stage, multi-level production;
- develop tools to help determine the Master Production Schedule;
- choose a Master schedule;
- control the aggregate workload;
- use simulation models to evaluate the appropriateness of push and pull planning systems;
- develop models of the extended enterprise;
- ensure that a detailed shop schedule is consistent with the master schedule;
- ensure that equivalent and comparable bases are chosen when comparing the performance of different production control systems. This is an investigation of the effect of different input-output transformations;
- understand and overcome system nervousness;
- determine the dynamic planning characteristics;
- estimate lead times;
- choose the system parameters including time related parameters e.g. planning horizons and planning frequencies and levels of aggregation for planning and control.

Provide support for administrative systems. Actions include:
- consider steps such as those listed in ‘Organisational and Procedural Actions’ in Section 4;
- choose an appropriate company structure for the product and market;
- choose the supply chain;
- choose the horizontal planning sub-divisions in the company e.g. between different shops, different products, different cells, etc.;
- choose the planning hierarchy;
- create systems that encourage Concurrent Engineering;
- retain integration as systems are changed;
- choose an appropriate system structure.

10. Understanding and Administering Changes to PPC Systems – An Example

Multi-product, multi-level production is very common, yet current methods for planning and controlling multi-product, multi-level production are not satisfactory. The most commonly used system is MRP but, as indicated in Sections 3 and 7, MRP does not completely meet users needs. The main needs include determining the MPS, overcoming the contradictions related to lead times and capacity, changing the MRP system representation from a static, deterministic representation to a dynamic representation, maintain highly accurate stock records, reschedule more easily, link MRP with design, link MRP with investment appraisal models, etc. The extensive needs, the ongoing difficulties and the importance of the appropriate planning, suggest that PPC of multi-product, multi-level production is suitable to illustrate how systems may respond to the kind of changes described in this paper. The rest of this section discusses how to use the ideas discussed earlier in the paper to improve performance.

Changing PPC systems takes time. There is therefore a choice whether to improve the PPC systems within the existing structure or whether to consider changing the structure. Whichever is chosen, it is useful to consider administrative, behavioural and quantitative actions that are needed to improve PPC performance. Administratively we want the system to work better. Preferably the administrative steps should include obvious simplifications, being consistent, improving the quality of data, etc, as discussed earlier. Behaviourally we want people to be involved and to operate the system better and this requires acceptance and ownership of the PPC system by the staff. The quantitative actions need to be based on sound theory.

For reasons of comprehension, a hierarchical approach to PPC is used. In MRP, the hierarchy is illustrated in Figure 3. The three steps are usually: producing the MPS, secondly the procedural breakdown into requirements of parts and materials and, thirdly, action plans interpreting the requirements into make (shop scheduling) and buy (purchase scheduling) decisions. Ideally one wants first to improve Master Production Scheduling, an area that currently is more of an art than a science. This can be achieved by choosing feasible solutions and then move some way towards optimised programmes. To make this more manageable these plans may be set into an aggregate long term planning context and the schedules may be split into plans for different shops, suppliers, etc. In the context of the framework shown in Figure 4 these are parallel actions in the disaggregation procedures. For discussion purposes improvements are considered within the context of the current system structure e.g. continuing to use MRP and maintaining the current levels of hierarchy which are assumed to be MPS, requirements planning and scheduling purchases and the shops. The main improvements under the administrative, behavioural and quantitative action headings are summarised in Table 2.

First we want a theory that can explain things. Secondly, we want to combine the theory with simulation. Thirdly, we want to turn the theory into operational actions. One possible way to proceed is to obtain better understanding by analysing MRP systems using conventional control theory analysis (transform methods) and the techniques of input-output analysis. Together they offer the opportunity to greatly improve the performance of MRP systems and, combined with simulation, they provide the basis for designing systems that have the required performance. These new theoretical representations of PPC can also represent logistics planning problems using the same modelling structure. Hence the same theory and structure may be used to model the complete supply chain, production with disassembly, recycling flows, reverse logistics as well as disposal, repair problems and design modifications occurring during production. Quantitatively, Laplace transforms, z-transforms and modern control theory and the other theoretical representations of MRP based systems discussed in Section 8.2, have improved our understanding of multi-stage, multi-level production-inventory. They offer the possibility of changing from static to dynamic representations and have improved understanding sufficiently that a research agenda can be set to improve system performance. First, Master Production Schedules, product structures, lot sizes, lead times, safety stocks, etc., and the process of MRP can be represented using matrix equations. Requirements planning problems can be represented in a consistent way whatever their size particularly with respect to the number of levels in the product structure. Matrix methods are essential for the mathematical formulation of these problems and, although the data is sparse, matrix solutions are no longer a problem with large storage capacity cheaply available with all modern computers. Secondly, by generalising the analytical and modelling possibilities of input-output analysis and control theoretic methods, multi-stage, multi-level production-inventory systems can be more fully understood, clear criteria set for improving their dynamic performance and values of the major parameters determined. The theory helps to derive feasible production plans and improve our understanding of how such parameters affect the dynamic performance of an actual or proposed manufacturing system. The theory may be used for evaluations from feasibility studies to system optimisation. It provides shortcuts for evaluating the impact of changes in the market and technical environment at the shop-floor level. It thereby offers additional flexibility to companies with consequences that should be better system

Table 2 – Summary of actions to improve PPC System.

		Administrative actions	Behavioural actions	Quantitative actions
Input	MPS	Improve MPS realism using resource planning	Agree actions on make, order acceptance and financial control	Improve MPS realism Simulate proposed MPS
	Data	Improve and maintain data e.g. product structures and stock records	Encourage Ownership of data	Use new methods to derive data automatically
System	Planning	Formalise the planning steps Improve shop scheduling	Training and team working Work better with suppliers	Improve requirements planning, resource loading and shop scheduling methods
	Control	Improve feedback Improve rescheduling	Use local visual load control and combine with best features of JIT	Model planning and control as in 8.2
Output	Plans etc	Improve MIS and documentation		

responsiveness, better schedule adherence and better delivery performance. Inventory levels will be reduced. There are still practical problems and limitations of the theory e.g. an outstanding problem is how to deal with rescheduling. However, the potential economic gain from using these methods is great.

An input/output model of an enterprise can be decomposed into a set of local models, with overall constraints to ensure that total system performance is maintained. The display, retrieval and communication abilities provided by modern information technology can then be utilised in combination with local modelling to provide improved and visual methods for local control. As well as local within the manufacturing unit, this becomes important when including the upstream and downstream activities of the supply chain. The development of e-commerce raises the possibility of an integrated system with suppliers and customers entering data, offering suggestions and making evaluations on new schedules in a proactive manner.

Developments in computing power enable the inversion of large-scale matrices to be performed in real time. This should allow the theoretical developments to be turned into robust and responsive practical planning methods. These planning methods can be used to determine master schedules and perform capacity planning in a dynamic situation, determine when and how best to reschedule, vary lead times according to the workload and decide how to deal with uncertainties, safety stock and safety lead times. There is a need for prototype software that can perform the above tasks, so that the methods may be tested in companies and so that the performance of the proposed system may be simulated and operational systems tested. These developments also need to be tested operationally in combination with local visual control. This will allow managers and schedulers to use their personal knowledge of the situation to identify problems as they arise and adjust proposed solutions by taking account of problems that are known to be present but are not formally modelled. The prototype system could use object oriented integration methodologies to provide flexibility for future developments and to allow the analytical tools to share information generated by other manufacturing enterprise design tools. Cash flow considerations could be included in the methods to allow the time phased economic consequences of different plans to be evaluated as decisions are made.

The methods used in the research are applicable to the whole logistics chain. They link with design for manufacture choices e.g. determining the number of levels of assembly with knowledge of the eventual planning and scheduling consequences. They can also determine the levels of accuracy that are required to operate such systems effectively. Hence, although these ideas relate to production planning and control, the applicability of such results is much broader.

11.Summary and Conclusions

Production planning and control is probably different in every company, yet the need to determine when and how many items should be produced is common to all. It is interesting to ask whether changes to manufacturing and information technology will, by speeding up manufacture and ensuring better data accuracy etc., eliminate the need for PPC in its present form. Alternatively should the emphasis of production control change to meet the challenges of the different technological and market context? The author's opinion and the discussion in this paper have indicated that PPC systems need to change so that the emphasis of PPC will be on how to design and manage manufacturing operations for responsiveness, globalisation and supply chain issues. If so, the proposed research agenda should also reflect these new needs in addition to the problems that remain from current technology such as MRP as described in the previous section.

This paper has discussed the needs of PPC arising from changes occurring in the market and in technology. One of the needs is to obtain a better understanding of PPC. Some steps have been proposed that would help to achieve this better understanding. It has been suggested that it may be advantageous to consider PPC systems quantitatively. Yet, at the same time, it has been recognised that the behavioural and organisational effects of changes also need to be considered. There is a need to examine these problems in a generic way.

Despite the length of this paper there are still many unstated assumptions. The implicit model used to develop the needs of PPC is a hard systems approach that is nevertheless holistic in that it provides a clearly defined framework within which softer issues may be incorporated. The work has been set within the context of enterprise design tools and enterprise databases. Some of the proposals such as the structured analysis representation of the product introduction process clearly link product design and marketing issues to planning and manufacturing. Different design for manufacture proposals may also be evaluated within this hard systems framework and so this model may be used as a simulation to assist decision-making.

Success with the proposed research agenda would provide new methods that would enable the feasibility of plans to be more thoroughly checked with regard to resource availability and stability prior to their acceptance. Hence manufacturing and purchasing requirements are more likely to be achieved. System visibility should be improved so that appropriate remedial action can and will be taken by the users in response to over-loaded or under-loaded resources. One method for this has been outlined. The high visibility and better capacity planning will make it more likely that performance will match plans. Thus rescheduling arising because of limitations in the planning procedures will be required less frequently. However the need for rescheduling will still arise in response to external events such as changed demand or delivery failures.

To control production and produce items on time requires turning a people system into a near deterministic system. Yet this needs to be done by a system that will for the foreseeable future still be a socio-technical system. To do this requires a better understanding of how systems perform if they work as planned. More difficult is that PPC systems then need to be designed and implemented so that they can work in conjunction with people. For example, if the locations of the parts or the hours required to make a part were incorrectly recorded, any plans derived from these records would be unrealistic however well understood were the quantitative relations between the variables. The system operation would then rely on human intervention. Hence, in addition to better understanding, better system performance requires appropriate data and systems designed to enable people to use their discretionary abilities and take appropriate remedial action when required. This will continue to be true in the dynamic situations that arise when introducing new products into production.

There is a need to develop and exploit the ideas and theoretical approaches outlined so as to achieve major improvements by reducing costs and improving delivery performance of manufacturing industry. In particular, better understanding of human systems, human capabilities and human needs is required. Additionally, there is a need to consider dynamic simulation and possibly links between investment appraisal of products and processes and the PPC procedures. These ideas need to be related to the size of a company because if a company is small, the management informally knows what is going on and so many of the human and communication problems disappear. However, when a company grows, the nature of management control changes. Large companies potentially can use the automated methods.

Many research and administrative problems of PPC have been lightly touched on. However, much work is still needed to improve our general understanding and performance of PPC. This is particularly true of MRP, the example chosen to illustrate some of the ideas presented, but equally well, many topics other than MRP could have been chosen. It would therefore be useful to have a research programme that links theoretical investigations and practical system operation in order to gain this greater understanding. The benefits to be obtained are great and the challenges are many, exciting and worthwhile. It is hoped that after refinement the ideas will move forward from the lengthy wish list presented in this paper to create a structured action plan and research agenda. This is currently being worked on.

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REFLEXÕES SOBRE O PLANEJAMENTO E CONTROLE DA PRODUÇÃO (PCP)

Resumo

O artigo examina o estado da arte do Planejamento e Controle da Produção (PCP), identifica algumas mudanças técnicas e nos sistemas que têm ocorrido em anos recentes, e as relaciona com as necessidades que estão sendo colocadas nas companhias pelo mercado. O PCP está sendo solicitado para responder efetivamente a essas mudanças internas e externas, para ser mais dinâmico e fornecer um melhor controle dos recursos e desempenho nas entregas. Algumas das necessidades a serem satisfeitas pelos novos sistemas de PCP são identificadas. Para atender essas necessidades é sugerido que é preciso um melhor entendimento de como diferentes fatores afetam o desempenho dos sistemas de PCP, e que os sistemas administrativos precisam melhorar. Os aspectos quantitativos, administrativos e comportamentais do PCP são discutidos. Uma estrutura para desenvolver uma agenda de ação e pesquisa é proposta.

Palavras-chave: planejamento da produção, controle da produção, visão geral.