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The origin of materials requirements planning in Frederick W. Taylor's planning office

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The origin of materials requirements planning in Frederick W. Taylor's planning office

Abstract

Materials Requirements Planning systems appeared without significant provenance. Their theoretical and practical antecedents can be traced to Frederick W. Taylor's Shop Management that described a production planning and control system comprised of functional foremen and clerks. This system failed for it was too complex, unwieldy and expensive. Nevertheless, some elements survived- for although the whole was unmanageable a few individual functions survived as independent sub-systems. These continued in use; with Taylor's planning office remaining an ideal and well known theoretical construct. The planning office imposed unbearable information processing demands on contemporary manual systems. But from the mid-1930s accounting machines started providing more capable information technologies that first allowed these individual elements to be implemented as stand-alone applications. Later they were then integrated into more full systems. Taylor's planning office provided the sub-system pieces and the conceptual framework for their subsequent recombination and extension. This paper traces the evolution of production planning and control systems from Taylor's planning office to materials requirements planning systems. Not only are the linkages between production management thinking in the different periods unappreciated; but so too are the technological relationships between the information technologies used.

The origin of materials requirements planning in Frederick W. Taylor's planning office

1. Introduction

Production management has progressed significantly over the past century. Current Enterprise Resource Planning systems are derived from 1970s Materials Requirements Planning (MRP) Systems (Jacobs and Weston, 2007) that Mabert (2007) shows are developments from 1940s production planning systems. Mabert (2007) claims they used 'the general logic' of MRP systems. Skinner (1985: 79) observes that these early systems were '…in effect a computerless form of MRP… with the calculations done by the business machines of the 1920s and 1930s.' These historical developments are not widely recognised or accepted: Harris' (1915) economic quantity models and its later variants are considered by Gilbert and Schonberger (1983) and Rondeau and Litteral (2001) to be the predecessors of MRP. This latter view is questionable since Orlicky (1975: ix) pointedly observed that: 'Materials requirements planning has become a new way of life in production and inventory management, displacing older methods in general and **statistical inventory control in particular**….' [Emphasis added] The profound incompatibilities between MRP applications in dependent demand production and Economic Order Quantity (EOQ) models best suited to inventory control in independent demand applications further confounds the possibility that the earlier EOQ models evolved into the later MRP systems. Mabert's (2007) unsubstantiated assertion about the capabilities of 1940s systems requires documentation; and their provenance and development further investigation. This paper provides a longitudinal study of the development of production planning and control systems over a 70 year period, comparing Materials Requirements Planning to Taylor's Planning Office both conceptually and operationally; and traces their implementation across contemporary information technologies: manual methods first, then crudely automated using electro-mechanical "accounting machines" until those yielded to electronic data processing systems and ultimately modern computers.

The functionality of 1940s systems will be described and their origins identified. These implemented Taylor's Planning Office (Taylor, 1903, 1911; Thompson, 1914, 1917; Elbourne, 1918). These planning and control activities only became practical once information processing systems became powerful enough to deal with the volume of data and complex analysis required. Planning Office activities were initially performed in the early 1900s by hand with card-based information processing and analysis. After the late 1920s these information processing tasks were increasingly transferred to accounting machines, electro-mechanical information processing systems. These further developed so that by the late 1940s and 1950s they then lead onto digital computer technology. Orlicky (1975: 6) observed that the chief obstacle to implementing MRP before the 1960s had been insufficient data handling, manipulation and computation capacity. Despite these inadequacies, Taylor's Planning Office introduced many ideas and practices found in MRP. Materials Requirements Planning systems remain important today, a survey cited by Bartholomew (2006) found 80% of the best manufacturing plants used it and another 8% intended to do so; and its logic is used very widely even in non-manufacturing concerns. An understanding of MRP/ERP is considered essential knowledge for operations managers.

2. Methodology

Historical research methods seem subjective with events and data often yielding a variety of differing interpretations. In this case the complex links between production management systems and contemporary information technologies; the influences on them both, and their own influences on later ones will be assessed. This study identifies numerous similarities and consistencies at specific times, and across time to establish that these historical influences are valid inferences. The evidence builds the case that Taylor's Planning Office's functions and their coordination and integration provided the conceptual and practical foundations for subsequent production management systems and ultimately underpinned MRP systems.

Although Taylor is the most prominent management theorist (Kanigel, 1997), and Drucker (1954) considers his Scientific Management the most important American contribution since the Federalist Papers the preponderance of attention focusses on that and not his contributions in Engineering (high-speed steel and machine shop practice) or production planning and control (Functional Foremanship). This study intends on remedying that by showing that Taylor's system survived and influenced later developments, and that evolving information technology systems played a vital role in their early and subsequent implementations and re-integration. Given the seventy-year long period surveyed, the different technologies; manual, electro-mechanical and then digital, and varying management environments, it is unsurprising that this evolution has been unrecognized, even by other historical reviews such as Mckay (2003).

The data was collected from a comprehensive literature review concerning production management systems from 1904 through the mid-1970s. Taylor and his immediate circle's (Gantt, Galbraith, Barth, etc.) writings were reviewed, as were contemporary commentators (Thompson, Clark and Elbourne) to establish a starting position. Orlicky and proponents (Plossl, Wight, etc.) of MRP provided an ending position. Links between them were sought in the intervening literature. Prominent later commentators such as Alford (ASME president after Taylor), Diemer, Kimball and Porter were investigated; publication lists from major publishers in the genre (Macgraw-Hill, Ronald Press, and Reinhardt) were reviewed; and citations found in all these were pursued. The periodical literature was investigated too. In addition, documentation on the differing period's information technologies was reviewed. The earliest treatments were found in discussions of production management systems. Then, as accounting machines became more widely used, the accounting literature started covering these systems. Later nascent information technology publications provided information discussing system implementations from journals, conference proceedings and research monographs, as have modern histories of information technology. Some documentation came from proprietary documentation from IBM. This evidence should be authoritative and comprehensive though the nature of historical research makes it impossible to be fully exhaustive.

Our argument that these systems should be considered influential follows from the mass of material and its popularity. The figures shown later are not obscure or easily overlooked. Alford's Handbook was published in numerous editions over many years (Jaffe, 1957). MacNiece (1951) published numerous printings over several years. Koepke (1941, 1949, 1954 and 1961) published several printings over 3 editions. The flow charts shown also originate in books well known to the industry. The literature cited was well established and easily available then and even now.

The information technologies used to implement these concepts and practices were more difficult to identify. Until the 1930s discussions of Taylor's system often showed illustrations of the forms used with details of their information and its processing. The advent of accounting machines and mechanised information processing lead to less attention being given to these aspects in the production management literature. Documentation on accounting machine implementations has not been so readily available since general treatments provide little discussion of operational concerns apart from inventory accounting, and the more specialised treatments are superficial overviews provided by manufacturers or user reports. An important aspect of our argument is that system developers and users would have used their experience with manual and accounting machines when developing MRP. That knowledge is almost invisible for it has not been well referenced; and a number of potentially useful proprietary sources haven't been obtainable, a common difficulty in historical research.

3 The planning office's rise, fall and revival

Production planning and control systems are inherently complex and difficult to understand. It is unfortunate that the Planning Office was not well described in Taylor (1903). Copley (1923: 173) notes 'Brevity was gained at the cost of a general failure to explain things in sufficient detail to establish their real significance.' Better descriptions (Nelson, 1980) of Taylor's systems and its operations are found in Elbourne (1918) and Thompson (1914, 1917). The Planning Office failed for many reasons but a significant factor was its heavy demand on manual information handling and processing. Further significant issues arose with its organisational demands in requiring specialised staff performing specific planning, coordination and control activities. The Planning Office's functional foremen may not be readily recognisable to modern readers. This reflects an increasing professionalization of roles, status and nomenclature: When Taylor spoke of 'bosses' and 'foremen' these roles are now filled by managers, supervisors and engineers. Where Taylor spoke of 'clerks' these positions came to be filled by planners and schedulers. Taylor's archaic terminology creates a dissonance that artificially separates current roles from their historic equivalents. The Planning Office was a complex solution to very difficult problems in production management and inventory planning and control. Taylor operated in a less sophisticated organisational atmosphere unreceptive to complex organisational solutions and possessing less effective information technologies.

Copley (1925) maintains that only four companies fully implemented Taylor's system and he does not identify them. Person (1929) provides a broad survey of the wide use of scientific management within American industry but Taylor himself (Copley, 1925) often considered many of these uses to have been restricted. The literature on Taylor's planning office typically considers it to have failed. Drucker, 1954 maintains that scientific management more generally had been stagnant for many years; just as newly emerging digital technologies were about to revitalize Taylor's planning office's functions within modern production planning and control systems.

The capabilities and operations of 1940s production planning and control systems will be reviewed; and their derivation from Taylor's Planning Office shown. **Best practice** in manual and later accounting machine systems will be the focus rather than **common practice** that was often crude. Taylor's Planning Office shaped subsequent developments by setting patterns for planning and control methods and systems. Figure 1 shows the evolutionary path envisaged. Taylor's Planning Office was not entirely his invention and drew upon a number of unspecified sources (Taylor, 1886) as well as his own experience (Copley, 1923; Kanigel, 1997). It is a synthesis of contemporary practices into a coherent whole.

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Taylor’s Planning Office did not completely die- it could be said to have fragmented because various functions were well considered and continued as independent activities, just as they probably did **before** Taylor’s synthesis brought them into an integrated system. An example is Taylor’s Balance of Stores Clerk and inventory management methods that were used effectively without requiring other Planning Office activities. Other roles in inspection, time-study, routing, etc. could also be used independently. Partial implementation yielded benefits, though not so great as if the whole were possible, or practicable. Many Planning Office functions survived as independent activities (Alford & Bangs, 1945; Mitchell, 1939). Alford and Bangs (1945) describe how the functional foremen evolved: Taylor’s ‘Gang Boss’ was replaced by two, ‘Set up’ and ‘Move’ men. The ‘Speed Boss’ evolved into an ‘Assistant Foreman’. The ‘Repair Boss’ and ‘Inspector’ became whole departments for repair and maintenance and for quality control and inspection. Taylor’s ‘Time & Cost Clerk’ evolved into two departments- payroll and cost accounting. The role of the ‘Instruction Card Man’ became the new profession of industrial engineer. The ‘Order of Work Clerk’ became the new ‘Schedulers’ and ‘Machine Loading Planners’. Taylor’s Planning Office was acknowledged (Alford and Bangs, 1945; Mitchell, 1939: 292) as the foundation for production management. It was so well known (Kanigel, 1997) that references were not needed (and common practice in the 1940s and before seldom cited sources as well as modern conventions would dictate). The Planning Office ideal was a useful framework for aligning the functional foremen and clerks with their 1940s and later equivalents.

Taylor’s introducing the whole system was not successful but significant elements of survived through the 1920s and 1930s and their manual information systems provided foundations for developing accounting machine applications. Inventory management was implemented as an accounting function (Schackel and Lang, 1929), but its extension to production control was apparent and Taylor’s systems provided a production management perspective on that. The reintegration of these planning office functions is comparable with the sequentially phasing in of functional subsystems until complete as often done with subsequent implementations of MRP.

3.1 From punched cards to MRP

Only manual information systems were available to Taylor’s Planning Office. Information was stored, transferred and processed using hand-punched and hand-processed cards (Evans, 1911, Metcalfe, 1886: 475-6; Taylor, 1886; Thompson, 1914, 1917). Taylor used the best information technologies then available. The Planning Office used both stable and volatile data: ‘Master’ Data. Much information did not change often and many cards recording it were ‘static’. Bills of materials, routings, work methods and standards were stable. These records were held in ‘Master Cards’ library to be duplicated as needed for distribution and use. Other information used for planning, coordinating and controlling factory activities was volatile: cards directed workers to use, move material and to perform specific operations any time such activities were needed. Cards were used to coordinate supplies from varied sources at varied times and places for timely assembly. Move cards directed output from a process onward to downstream activities. The cards provided management feedback by being passed back and forth between the Planning Office and the shop floor as the work was first issued, as it progressed through the required processes and the completion of each reported. With many customer and production orders, processes, employees and products the Planning Office generated hundreds, even thousands of card records. Controlling card issues and their handling required discipline with formal methods and systems. These card records were later called a ‘unit record’ (IBM, 1936) showing a specific instruction or the outcome of a given activity. Cards were a preternatural design and operational choice:

1 They were made of a more robust material than paper pages or ledgers. Individual cards provided a single record that would be easily transportable and usable. Bound ledgers would only be accessible to a single user at a time. Single pages could be almost impossible to track and were too fragile for most factories.
2 The original manual system designed cards in convenient sizes, colours and formats. Mechanisation imposed standardisation but initially designers had great freedom in designing record formats; and even later applications allowed some flexibility as shown in Casey and Perry (1951).
3 For accessibility cards were easily mounted in racks or hooks, or for secure visibility mounted under glass; and for portability they could be sized to fit workmen’s pockets..
4 Each card could be easily changed as the data or its format varied; or as managers changed their information collection, dissemination and analytical requirements.
5 Most significantly, managers and workers could physically punch cards to record, retrieve and analyse data. This maximised functionality making the recording of data its first step for processing and analysis. Figure 2 illustrates how cards could be punched and readily sorted or searched by hand.

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3.2 Efficient internal communications

An information network capable of dispatching and collecting cards throughout the factory was essential. If employees all had to queue for every card the Planning Office would be overwhelmed; and output and wages would be lost. Efficient internal mail systems were critical, providing regular; even hourly (Evans, 1911: 171-2), communications. The planning office closely tracked when activities began and finished by using time clocks for accurate reporting. Taylor insisted on written records recognising that verbal and later telephonic communications were less reliable, offsetting their speed and convenience.

3.3 Card based data analysis

Cards provided managers with information on activities and costs (Thompson, 1917). They were particularly advantageous for analyses. Materials and labor usage could be found by manually (or later mechanically) sorting cards by ‘order’ and summing; and then a running total for usage to date. Such usage information could be combined with cost data to yield both ‘process’ and the ‘total to date’ order cost. An employee’s wages would be determined by sorting cards by workman to find their output, combined then with appropriate piecework rates to yield wages payable. The machine utilisation rates were determined by sorting by machine and totalling to get overall usage, noting that down-time, maintenance and repair data too would be collected. Key information processing activities were sorting, collating and totalling information to provide management reports and analyses. Thompson (1917) observed that these processes gave managers exactly the information they needed quickly—on the next day. He contrasted that with end-of-month reports produced by contemporary accounting systems. This information was cheap because data collection and basic reporting was already being done to manage production. The additional sorting, collating and calculating required were modest extensions; the labor intensive and difficult work of creating (punching cards reduced the need to manually rewrite or reproduce that information), then gathering and distributing the information was already done and most of the costs incurred.

Large factories generated insurmountable information workloads for manual methods. Forms and documents shown by Thompson (1917) are hand-written or typed. There was no significant mechanisation of these tasks before the 1930's. The mathematical capabilities of early accounting machines were minimal: before 1928 they could only add, multiplication was introduced in the 1930s, and division only in 1946 (van Ness, 1967: 16). Taylor's Planning Office functions were implemented as stand-alone systems on accounting machines. Twyford (1918: 115-6) describes early machine bookkeeping as applied to conventional accounting clerical work controlling inventories, rather than within the Planning Office's framework. Sanders (1928, Vol. 3: 93) observed that the number of users and the variety of their needs were growing. Clark (1925: 66) also discussed cards but these contained written information for manual processing rather than punched data for electro-mechanical processing. Bennett (1926: 17) describes accounting machines used for inventory management. Anon. (1955), Buse (1957), IBM (1961), Porteous (1937) and Stevens (1945) provide examples of stand-alone functions of the Planning Office implemented using accounting machines.

These applications became more integrated from the late 1930s through the mid-1940s (Hill, 1963; Moore, 1951; Porteous, 1955). Taylor's system by the late 1940s was achieved by an integrated production management system implemented using electro-mechanical accounting machines. This provided both conceptual and physical foundations for later digital systems. Accounting machines provided well developed, reliable and effective technologies for data entry, sorting, storage and output through cards; and for printing. The accounting machines' use of relays switched either 'on' or 'off' was a 'digital' technology demanding essential, basic mathematics (addition and multiplication, followed by complementary mathematics for subtraction and finally, division). Although later, more sophisticated scientific applications stimulated digital computing advances it should be clear that their foundations lay in the prosaic business requirements served by accounting machines: 'We know that many of the technological developments in computing that were possible in the 1940s and 1950s came from the more immediate past.' with 'The focus should be on the equipment (technical considerations) and the uses for these in offices. This latter point—applications—is of particular significance because it encouraged many to look for better ways to perform common counting and accounting functions (Cortada, 1983).'

Accounting machine applications were 'programmed' so data was used to produce the necessary results and reports. This was done using plug boards that could be removed and manually configured using jumper wires for various applications. Multiple plug boards could be used and stored so frequent or complex applications were readily at hand (van Ness, 1967): early stored programs comparable to current game machine cartridges. This increased equipment flexibility and cost effectiveness by facilitating changing applications. By the mid-1930s accounting machines reached the point where they could be used for common production planning and control activities; individually at first, and then combined for greater functionality through systems integration.

Cortada (1996: 168) recognises the difficulties bridging the different ‘generations’ of digital computers. Without a ‘migration path’ each generation had to recreate applications already developed. This gulf is wider for the earlier accounting machine technologies. The MRP literature shows virtually no citations of earlier developments of production planning systems implemented on accounting machines; Orlicky (1975: 119) has the only one known. When implemented on accounting machines these complex management systems required numerous, time consuming runs for reading, sorting, replicating, computing, punching and printing cards and reports. Although the data management and technical challenges were significant the underlying concepts were readily transferred from manual to electro-mechanical systems and subsequently to digital technologies. Carlin (1958) identifies a developer that selected its client in 1952 for their experience with a similar accounting machine system. Grieser (1954: 169) describes a conversion from an accounting machine to a digital system. Caplan and Schatz (1959, p 245) discuss a similar case: ‘The existing card system was adapted to computer handling with a bare minimum of change.’ Haigh (2009: 7) observes that managers introducing digital computing had ‘extensive’ backgrounds with accounting machines, and that experience had a ‘profound influence’. Cortada (2000: 134) believes: ‘Tabulating technology is a particularly important forerunner of computers because the users of tabulating machines would be the first adopters of computer technology….’ This linkage between accounting machines and digital computing generally is also true for production management systems. It is inconceivable that IBM and other developers would have ignored decades of theory, practice and experience embodied in accounting machine implementations when developing their digital replacements. Users and systems developers would have known the earlier implementations and that knowledge would have been used. Although ‘migration paths’ did not exist the earlier theory, experience and practical knowledge was surely influential.

4. MRP and the planning office functions

Miller and Sprague (1975) provide a framework for comparing the basic functions of MRP and the Planning Office. They identify four central functions in MRP: the Bill of Material (BOM) File, the Inventory Status (IS) File, the Master Production Schedule (MPS), and the MRP Logic package. These will be used to compare the Planning Office to MRP. Information on MRP will be drawn from Orlicky (1975) in addition to Miller and Sprague (1975). For information about the Planning Office the sources used will be Elbourne (1918), a popular general production management book (Urwick and Brech, 1966) with more detailed information on the Planning Office from Thompson (1914, 1917). The Planning Office is ‘modern’ in understanding the simultaneity of managing both production and inventory: ‘The subject of stock control is so intimately linked up with production efficiency….’ (Elbourne, 1918: 153) He discusses the Planning Office in a basic manner comparable to Miller and Sprague's (1975) discussion of MRP.

4.1 Bills of materials

MRP systems are dependent on identifying the correct components, their inter-relationships and accurate quantities for production planning. Bills of Material (BOM) are thus essential for these systems to be effective. MRP systems apply great effort to ensure that the Bills of Materials are correct. The Planning Office was equally cognizant of the importance of BOM accuracy:

> It may seem an ultra-refinement to specify every nut, washer and cotter pin, but it must be borne in mind that the right quantities have to be learnt at some stage of production for issuing the details to the fitters and erectors (Elbourne, 1918: 133).

This substantiates Mabert's (2007) belief: Figure 3 reveals that 1940s **best practice** in production planning systems used **exactly** the same logic as later MRP systems in making a level-by-level BOM 'explosion' complete with 'netting'. Figure 3 (Moore, 1951) is attributed to IBM and dates at least to 1945 where the graphic (though not the accompanying text) is in the *Handbook* (1945: 231) edited by Alford and Bangs. Alford was an early advocate of systematic management and although often critical of Taylor's work he promoted its most effective features. The mid-1940s understanding of the BOM explosion is identical to an earlier description in Thompson (1914, 1917), and with that of later MRP systems. It processes BOM data level by level, with higher level demands satisfied first by on-hand stocks at each level, and then projected requirements imposed down the product structure and accumulated until the items at lower levels are processed. This yields a detailed production plan for all finished items, assemblies, sub-assemblies, components and other inputs.

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A crucial shortcoming is its failure to show time-phased requirements. There is no explicit recognition in the Figure that the various inputs must be produced or purchased at different times depending on their lead times. Nevertheless, lead time off-setting was recognised as an essential element in coordinating operations:

> There will be considerable differences in the time necessary for piloting the respective components through their various stages of production and this means that there ought to be all that difference in the time of starting work on the components, if delivery of the whole set or sets is to be synchronised at a given date (Elbourne, 1918: 170).

so that: 'The time at which the last component for a given complete product is finished virtually marks time of useful readiness of all the others (Elbourne, 1918: 170).' This is identical to Evendell's (1968) identification of time-phased planning with effective, 'modern' management. Figure 4 (Knoeppel, 1920: 323) illustrates time-phased production planning in a manner comparable to that shown in Orlicky (1975). The Planning Office's significant concerns with shop floor control (dispatching, material transfers, work study, etc.) made time-phasing central to their planning. Progress Charts shown by Gantt (1903) and Clark (1922) were used to coordinate operations across processes over time to meet deadlines. This critical feature seems forgotten when EOQs were adopted that 'scientifically' minimised inventory costs through inappropriate assumptions. Orlicky (1975) criticised the inherent inability of EOQ models to coordinate related production requirements.

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4.2 Inventory status

In the Planning Office the 'balance of stores clerk' managed inventory and outstanding orders using a specific form to monitor inventories and ensure materials were available to satisfy requirements. This used existing inventories to reduce gross requirements so the factory only produced to meet demand or stocking needs. Taylor's Planning Office preceded EOQ theory so the issue of what quantities to produce was open. Elbourne (1918: 171) recognised that increasing order sizes improved productivity by spreading set-up costs. However, he noted these benefits were often lost when customer's orders were expedited ahead of orders intended only for stock- the resulting lot-splitting then increased set up costs. The anticipated economies of scale were not achieved. A sales-driven approach seems to have been normal practice[1], Elbourne (1918: 153) suggested that: '... the practice of ordering practically all material only as and when required to meet specific orders has a great deal to recommend it.' to avoid excessive inventories. Despite that, production for stock could be useful so he suggested a reorder point

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[1] A digression on inventory management history: The operations management literature ignores historic alternatives to Economic Order Quantities. This oversight requires rectification. Whitin (1953) considers EOQs but briefly mentions 'hand-to-mouth buying', a lean approach in which producers make only enough for immediate needs. This policy became dominant after a crisis in 1921 (Lyon, 1929: 9-10) when a severe contraction in sales left many companies with dangerously high inventories. There are several references (Clark, 1927-8; Lyon, 1929; McGill, 1927; Tosdal, 1932-3) to it throughout the 1920s and 1930s and the survey undertaken by Lyon (1929: 6, 93, 275) shows it to have been widely used across several industries with discussions of it being 'general and profuse'. Lyon (1929: 424-445) describes the history of 'hand-to-mouth' buying, observing that it was normal practice for most of the 1800s. The effects of improving transportation and communications on production management are particularly interesting. In the very early 1800s buying and production was seemingly often based on an annual period, the difficulties of transport and communication dictated that distant customers ordered once yearly to meet all their needs. With the introduction of rail transport and steamboats the reducing cost and increasing reliability of delivery allowed more frequent ordering (Lyon, 1929: 444). This smoothed demand throughout the year but the basic, underlying principle of buying only to meet needs remained. Lyon (1929: 376, 458) also discuss the impact of improving communications, noting that telegraphy had the same effects in the mid-1800s as telephony in the early 1900s had on speeding communications (and we note similar effects email has now, a century later). Lyon (1929: 445) observes that the lowered costs and greater speed of rail transport echoed the earlier effects of canal building that allowed water transport to replace overland carriage. 'Hand-to-mouth' buying remained popular despite the EOQ's development, Lyon (1929: 450) implicitly refers to Harris (1913) when he observes 'The increasing acceptance of engineering ideals in production has, particularly during the past 15 years, been working its way into the buying and selling function.'. He speculates that increasing numbers of business schools will promote those methods. The Planning Office was driven by sales; the EOQ had not yet been invented. Indeed, Taylor's work created an atmosphere that encouraged such theorizing. Lean manufacturing may be rediscovering historic policies linking production to customer needs thereby reducing or minimizing inventories. The strategic pressures Lyon (1929: 448) found favouring 'hand-to-mouth' buying remain: the tensions between having too much vs. too little, having it too soon vs. too late, having too much variety vs. too limited stock; all these difficulties may be resolved by matching purchases to customers' wants.

technique:

> Not only should the ordering level be fixed but also the normal quantity to be ordered, and both must have regard to the time required for obtaining fresh supplies and the liability of the stock becoming exhausted meantime (Elbourne, 1918: 154).

The lot sizing technique is not described and no consistent method seems used. When orders are not dictated by sales then Elbourne (1918) suggested a fixed quantity approach. The planning horizon seems undefined, determined by customer orders and lead times needed. Inventory control ensured sufficient short-term stocks to satisfy production and sales requirements. The planning horizon was ambiguous and defined by business needs. Koepke (1941) vaguely describes a planning period of 'several months'. In the 1930s accounting machine implementations had fixed planning horizons dictated by design and processing requirements, as MRP also found necessary.

4.3 Master scheduling

The Planning Office seemingly was demand driven, scheduling production as orders were received. Production requirements (quantities, times, etc.) followed the logic implicit in the production process, as seen in Figure 3. The Planning Office had routings detailing the processes and their sequencing, it had balance of stores information to determine what assemblies, components and other materials would need to be made or purchased; and it had work methods and time study data so that it could direct workers to perform the work and accurately estimate the time needed. This was a complex planning process, one that individual workers themselves could not have performed. Indeed, Taylor asserts that no one manager could do it and that specialisation and sub-division were essential. Modern, large scale manufacturing requires coordination; what Taylor attempted with a manual system was replicated in the 1960s and 1970s by MRP. MRP's logic is imposed on production processes by a computer-based, batch-driven planning system. Much writing on MRP discusses its processing logic and operations with an emphasis on adapting operations (e.g., using non-descriptive part numbers, rigidly defined BOMs, etc.) to accommodate the requirements and limitations of computerization. The logic used in the Planning Office is identical with that used by MRP in coordinating the times and quantities produced. Differences between them reflect differences between using people or computers for handling and processing the information.

The MRP master schedule specifies the quantities and times when finished goods are needed and thereby dictates when all contributory production activities should happen. Figure 7 (Kimball, 1925: 158) shows a master schedule driven Planning Office, just as it would be for MRP. Production is driven by customer demands or management's ideas on the appropriate quantities of inventory. In many early MRP systems the master schedule was used as a buffer insulating production processes from demand fluctuations. MRP systems using 'zero' inventory policies are demand driven. Elbourne (1918) has sales stimulating production, and does not explicitly describe using planning to smooth sales variations. Clark describes (1922: 68-69) how plans are useful for managing sales fluctuations. When sales fall the plan can be used to identify products or periods where sales should be increased. The plan could also be used to identify workers or equipment to reassign to other products or jobs. Under sales increases the plan would show products or periods with lengthening delivery times and potentially unsatisfied or disgruntled customers; additional workers could be assigned to alleviate those problems. The plan would also help identify bottlenecks that need additional staff or equipment. Since sales were the driving factor a ‘Chase Demand’ strategy was explicit in planning.

4.4 MRP logic

High-level system flowcharts are a key tool for illustrating the scale and complexity of these complex production management systems. These provide an overall perspective on the various system elements and their operations. For comparison to MRP, Figure 5 shows a comparable system flowchart for IBM’s Computer Oriented Production and Inventory Control System (COPICS) from the 1960s.

Figure 6 shows a flow chart illustrating a 1940s production planning and control system (Moore, 1951: 332). This was implemented on accounting machines (Alford and Bangs, 1945; Moore, 1951; Parton and Steres, 1955) that were crude, slow and limited compared to computers (IBM, 1961). Alford and Bangs (1945: 230) describe an accounting machine based system used to control the production of over 1,600 end items made from 58,000 components using 8,000 different raw materials and another 14,000 purchased components. Of these, 60% of the components were used in multiple products, and there were significant differences in their lead times for both make-to-stock and make-to-order items. To further complicate matters there were large variations in sales.

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Insert Figure 6 Here

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The BOM was not as important in the Planning Office as it was for MRP. Taylor treated the BOM as just one of many engineering documents; specifications and drawings, routings, processing instructions were needed too and Taylor recognised the importance of them all in managing production. These others are typically ignored by the central MRP planning process, yet for the Planning Office they were vital for managing production. Moore (1951) illustrates the role of BOMs in accounting machine systems. A well defined product structure is a universal need for any production system, and can be seen in every discussion of production management and coordination. These include Moore’s discussion (1951) of the BOM explosion in Figure 3; and the use of BOMs in earlier systems in Kimball (1925), shown here in Figure 7 and in Sterling (1914) shown in Figure 8. These flow charts show an evolving and increasingly complex presentation of the Planning Office’s roles and their interactions.

<<<<<<<<<<<<<<<+>>>>>>>>>>>>>>>

Insert Figure 7 Here

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Insert Figure 8 Here

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Orlicky’s comprehensive discussion of MRP is not matched by any similarly clear explanation of a 1940s production management system, even Moore (1951); Parton and Steres

(1955) and Hill (1961) discuss only their general use but say little or nothing about their operating details. Schlesinger (1949: Figure 57) provides a pictorial flowchart showing people, accounting machines and cards, but with minimal descriptions of their functions and interactions. This paucity of information is seen later too in many treatments of MRP. These were often too superficial or narrowly focused to provide a sound understanding of the whole. Orlicky (1975: ix) was motivated to write by observing '… the subject of materials requirements planning has been neglected in the hard-cover literature and academic curricula, in favor of techniques that people in industry now consider of low relevance….' and goes on to say 'I found that the entire MRP literature consisted of twenty-six items—good, bad and indifferent—all of which were either articles, excerpts, special reports, or trade press "testimonials" (Orlicky, 1975).' The earlier literature on accounting machine implementations of production control systems reveals the same lack of documentation. The technical documentation for MRP is more extensive and detailed (IBM, 1975) with nothing comparable available for the earlier systems. My decade-long search for IBM (1949), IBM (1953), IBM (1954) and Traub (undated) may yet find these and allow a more detailed comparison. The best summary of an ideal punched-card based production control system may be Hill (1961), though it lacks Orlicky's (1975) thoroughness and figures illustrating its operations.

Figures 5 through 8 illustrate the evolution of Planning Office implementations. Modern MRP using digital systems is shown in Figure 5 with its high level description of the functions done. Figure 6 shows a 1940s accounting machine implementation with a similar level of detail in its description. This is a 'bridge' that shares diagrammatic features with later digital systems while the accompanying text links it to Planning Office functions and operations. Figure 7 from Kimball (1925) and Figure 8 by Sterling (1914) show the evolving representations of the Planning Office: Sterling's (and Diemer, 1914) is basic and crude, while Kimball's is more complete. Sterling's shows a basic manual system's functions and activities. Kimball extends that, though still using manual information processing. Moore's figure reflects their implementation on accounting machines.

4.5 MRP tableau

Perhaps the most useful feature of Orlicky (1975) are the tableaus that show explicitly the bill of material relationships, how current and planned inventories are used to determine net requirements, with lead-time offsetting yielding planned order releases; all over a fixed planning period. Each of these can be seen in numerous books (Alford and Bangs, 1945; and multiple editions throughout the 1940s and 1950s), Bethel, et al., 1942; Carroll, 1953; Fisher, 1928; Larkin, 1947; MacNeice, 1951; Parton and Steres, 1955; Porter, 1929; Ritchie, 1951; Simmons and Dutton, 1945; Tiranti and Walter, 1946) throughout the 1930s and 1950s, sometimes in conjunction with others; but no one puts all these together where the full system may be observed as a coherent whole.

Koepke (1949, 1954: 391; 1961: 151) presents the proto-tableau shown in Figure 9. This is the only pre-MRP example known. It has gross requirements, netting against on-hand stocks, projected requirements and order releases. It aggregates independent and dependent demands to find an item's gross requirements. This shows links to lower level materials but does not show their tableaus. The inference that these materials were similarly managed is inescapable, but there is no documentation showing that in a tableau. Other descriptions of the system's operations as shown in Figures 3 and 4 make that inference reasonable. DeCarlo (1955: 61) discusses a digital system in which end-item requirements drive the system: 'From this will follow the computation of gross requirements, net requirements after processing with inventory files, and capacity requirements after scheduling.'

<<<<<<<<<<<<<<<+>>>>>>>>>>>>>>>

Insert Figure 9 Here

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An earlier edition of Koepke (1941) discusses lead time offsets for coordinating deliveries and Master Schedules that combine forecasts with customer orders for 'several months in advance'. (Koepke, 1941: 392-3) Koepke (1941: 420) describes an 'accumulation form' used 'where there are a number of parts to be accumulated for an assembly or subassembly, some methods should be worked out to bring all the required parts together at the right time.' The conceptualisation of Tableaus appears to have arisen between 1941 because Koepke (1941) does not show them, and 1948, the date seen in Figure 9.

4.6 Capacity management

Poor capacity planning was a weakness of early MRP systems. This need was well addressed in the Planning Office by introducing a new production planning tool in the Gantt chart. The intimate connection between Gantt's Charts and Taylor's Planning Office is not widely known. They were sequentially published as papers 1002 (Gantt, 1903) and 1003 (Taylor, 1903) in the same issue of the *ASME Transactions* and meant to be read together as mutually supporting (Copley, 1923). Taylor and Gantt anticipated the difficulties that bedevilled later uncapacitated MRP systems. Production plans also need to consider capacity to be successful. Taylor's Planning Office relied on Gantt's charts to provide that function.

Gantt Charts were originally intended to be a general production planning tool. Porter (1929) shows applications in both make to stock and make to order production systems. MRP encountered significant difficulties in detailed capacity management and shop floor management. These were areas where Taylor's work-study and the Planning Office asserted great control. Capacity planning and work flow management were a central issue in Taylor's managing a factory's overall operations. Gantt (1903) developed his charts during the mid-1890s specifically to handle production management problems for individual workers, machines and for the factory as a whole. Clark (1922) describes how Gantt charts were used for meeting customer requirements:

> If a promise of a delivery is to be kept, all the work in a plant must be planned so accurately that when a new order is received, it is possible to tell almost to a day when the work will be completed. The Gantt Progress Chart enables the manager to keep before him all the promises he has made, to concentrate his attention on overcoming obstacles and avoiding delays, and, when it is impossible to live up to a promise, it enables him to give the customer advance notice of the fact (Clark, 1922: 84).

In this quotation there are three notable points:

1. The whole of the process was considered since Clark requires 'all the work' to be planned and controlled. Taylor's Planning Office subordinated the activities of individual workers and machines to the demands of the whole system.

2. The ‘all the promises’ implies that the factory is driven by sales, with no juggling of commitments satisfying current needs (e.g. ‘rush’ orders) using resources meant for future use (regular orders for normal delivery).
3. If the schedule is to be accurate ‘almost to a day’ then planning had to be precise. Delays and inefficiency could not be tolerated, and uncertainty would have been eliminated.

These imposed significant communications and coordination loads on a centralised planning and control system: it had to identify work as it was completed, move it quickly between workers, and ensure that a multitude of activities planned to start or finish simultaneously actually did so.

This is a complex theoretical and difficult practical problem. MRP was poor at resolving both aspects, although significant efforts were devoted to resolving these issues as the systems matured and became more widely used. Most notably, “rough-cut” capacity planning with “Bills of Capacity” were developed to attempt to address these problems. (Proud, 2007) Work in progress (WIP) in Taylor's system had to be kept relatively low to ease planning and facilitate shop floor co-ordination and control. (Clark, 1922) Reducing WIP also made controlling workers easier by limiting their options to only those for which the Planning Office had immediate needs. Work backlogs then would have been ‘planned’ as jobs finishing before later processes became available. This type of queue planning seems necessary for the plans and operations to be realistic. Because sales drove production plans these plans were also constraints on **later** sales. Existing sales dictated existing production plans with delivery dates being firm commitments to existing customers. New orders were scheduled as received, by their required delivery dates and had to fit in around existing production and sales obligations (Clark, 1922, Appendix 1). This reinforces the perspective that Planning Office was primarily sales driven. Once a commitment to sales was made the Planning Office then had a firm obligation to meet.

5. Conclusions

Mabert’s (2007) belief that 1940s production management systems used the logic of MRP can thus be substantiated. Although its elements were all available and used it is impossible to tell how fully these systems were implemented. There was no comprehensive description comparable to Orlicky (1975). It thus seems that individual implementations were idiosyncratic. Although the systems flow chart shown in Moore (1951) seems quite convincing strong doubts must remain about the extent and effectiveness of their implementation and use. The logic used in these accounting machine systems and their general operation itself originated yet earlier with Frederick W. Taylor’s Planning Office (PO) and his system of functional foremen. Taylor used **people** to provide the functions that later Accounting Machine and MRP **systems** fulfilled.

Further development of this research sees potential opportunities in investigating the sources Taylor used for identifying and designing the different elements used within the Planning Office. But he said nothing about where he found these in his articles or books. The difficulties in tracing modern articles and proprietary information on the earliest digital and accounting machine implementations have already been noted and those may reveal further dimensions to operationalizing these systems. More broadly, as Cortada (1983) noted these systems resolved many data processing problems with techniques and processes upon which modern systems rely, and the history of computing would benefit from investigating these more deeply, so studies such as this one for production planning and control systems might be replicated in other applications and management areas such as financial transactions and control systems or marketing with sales and customer management systems.

Sayles and Stewart (1995) observe selective perception and amnesia affecting developments in work flow management that apparently arise without reference to previous theory or practice. One striking aspect of the MRP ‘crusade’ (Miller and Sprague, 1975) was its sudden appearance without substantial provenance: many revolutionary concepts and practices came forward in MRP. As has been shown these ideas and practices had a long but unremarked history, some dating from earlier accounting machine implementations of production planning and control systems, but many more pre-dating those and originating with manual systems used by Frederick W. Taylor’s Planning Office. Taylor established a framework for later managers. Current enterprise resource planning systems now consider many features not found in the Planning Office, but Taylor also considered activities that current systems largely ignore. Taylor’s interests in work-study, job design and work methods improvement, as well as basic engineering and production organisation show a breadth of talent and ability. Taylor’s Planning Office was ahead of its time, and we might still learn from its engagement with these other areas. Initially the Planning Office was a failure, but the following century’s developments in information technologies—manual, electro-mechanical and digital eventually allowed its demands to be met. Organisations also grew and evolved so the multitude of functional foremen that Taylor’s contemporaries found so off-putting and costly eventually became the normal complement of managers, planners and other functionaries required by large, complex operations. The roots of MRP stretch back to Taylor’s Planning Office and its growth depended on a more advanced organisational and technological environment.

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Figure captions

a. ***Figure 1 caption:***
The evolution of production planning and control systems from Taylor's planning office through enterprise requirements planning
b. ***Figure 2 caption:***
Manual processing of hand punched cards
c. ***Figure 3 caption:***
Processing logic
d. ***Figure 4 caption:***
Time-phased production planning
e. ***Figure 5 caption:***
COPICS system flowchart
f. ***Figure 6 caption:***
Systems flow chart
g. ***Figure 7 caption:***
Manual system flow chart 1
h. ***Figure 8 caption:***
Manual system flow chart 2
i. ***Figure 9 caption:***
Production planning tableau

Figure 1

The evolution of production planning and control systems from Taylor's planning office through enterprise requirements planning

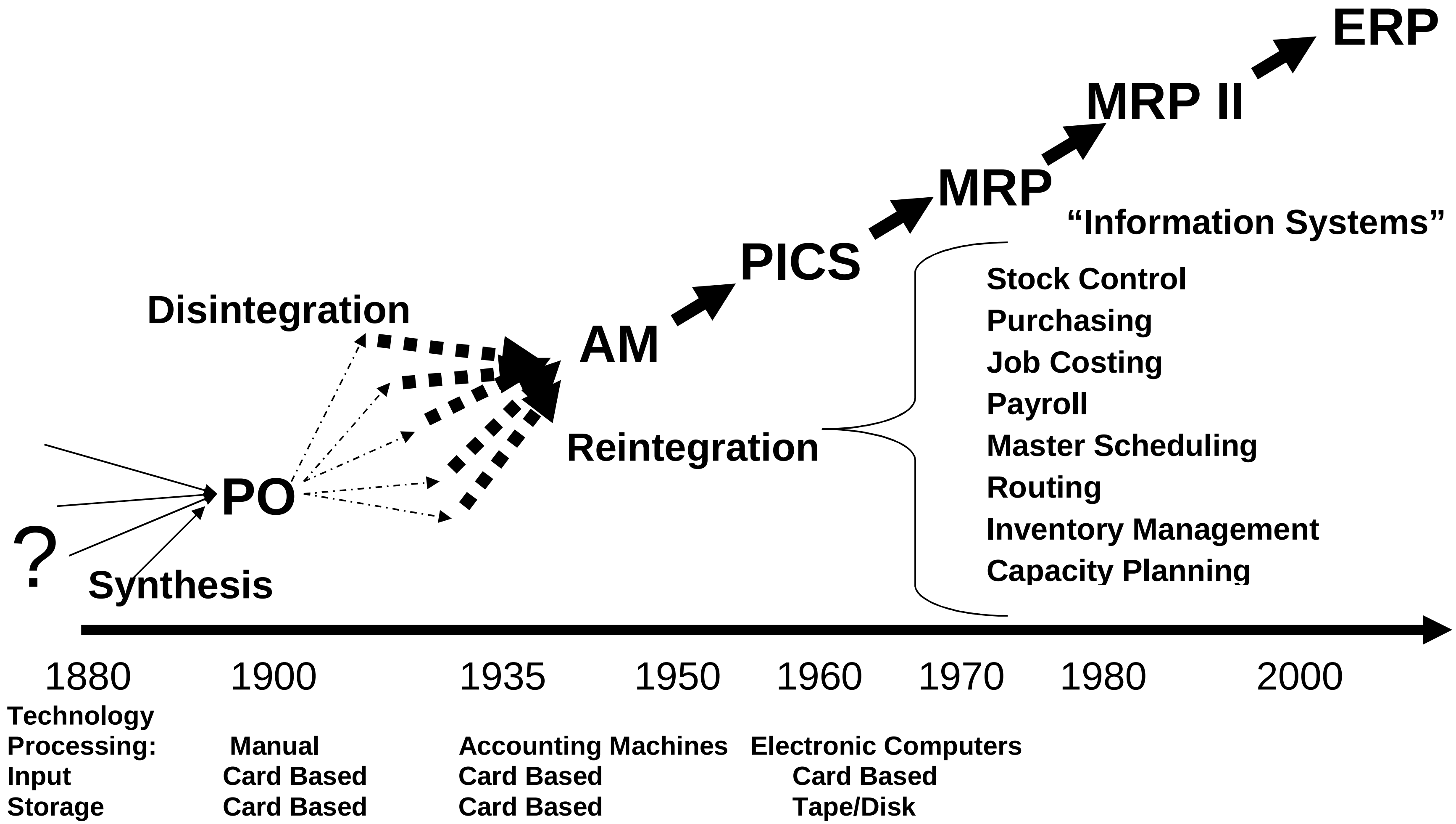

Figure 2

Manual processing of hand punched cards

MANIPULATIONS OF HAND-SORTED PUNCHED CARDS

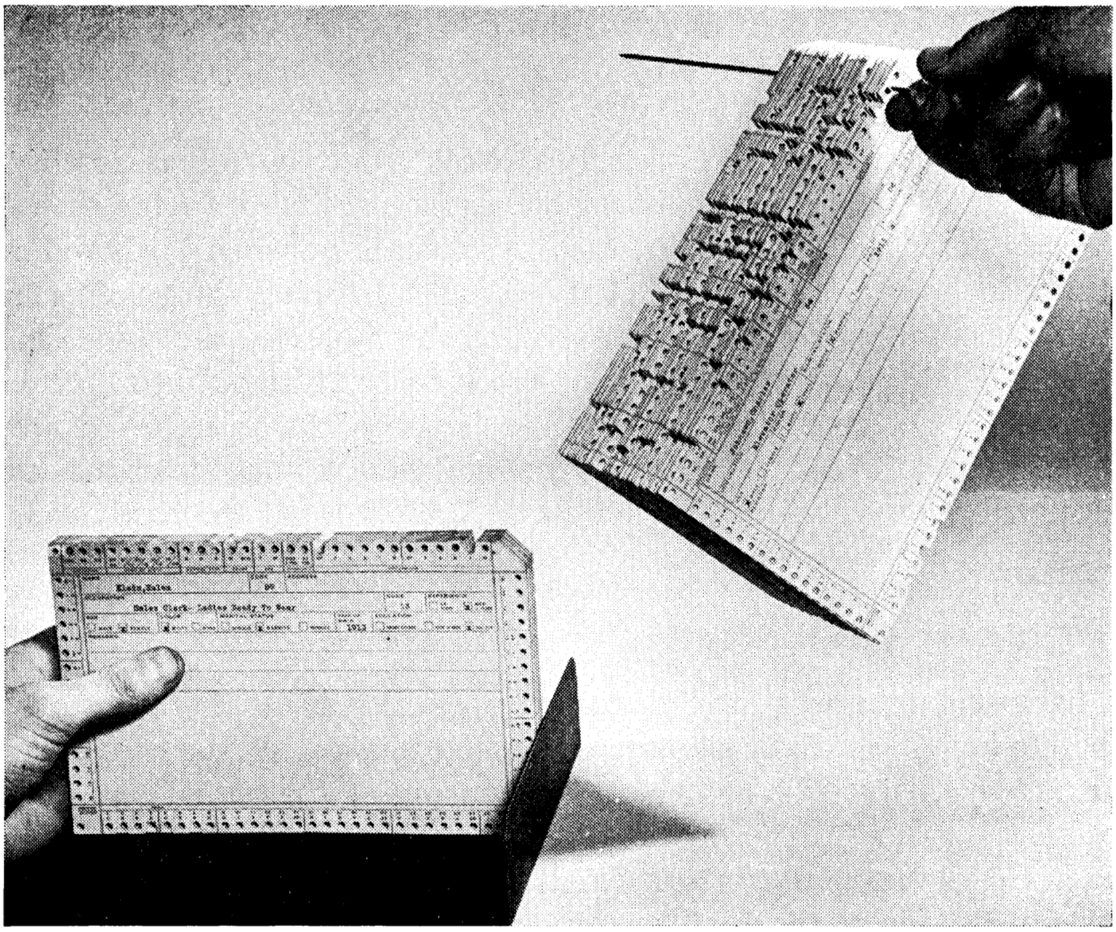

Figure 2-6. Sixth step—separation of selected from rejected cards is completed.

Casey (1958: Figure 2.6)

Figure 3

Processing logic

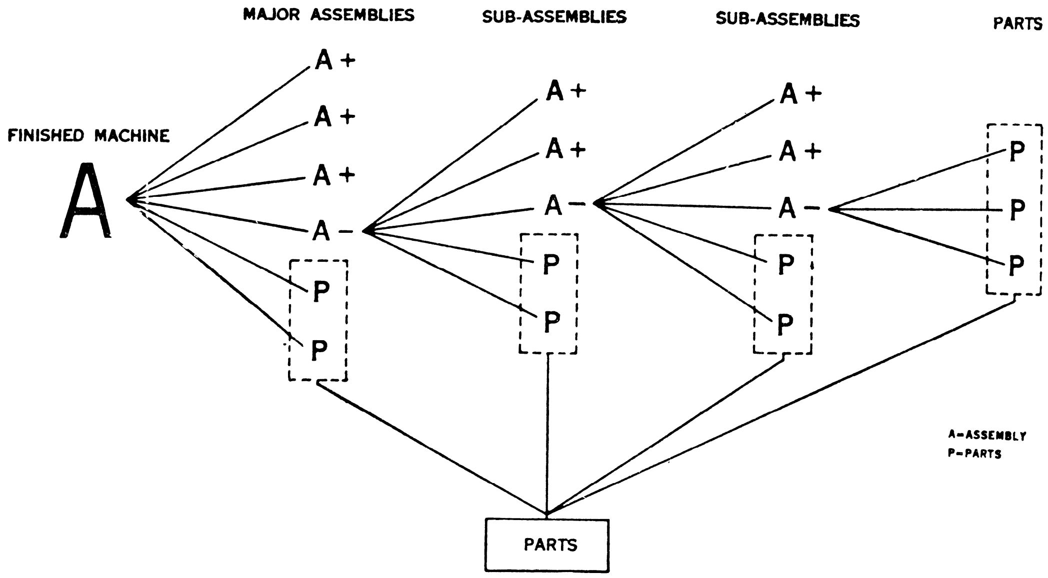

FIG. 14–7. A diagram of the "explosion" process as done on tabulating equipment. Starting with a card for product A, the card selecting equipment selects the subassembly cards and parts cards for all major subassemblies and all parts going directly into the finished product. The machine automatically prepares requirements cards for the subassemblies and parts needed. The parts cards are temporarily set aside while the subassemblies requirements are compared to their stocks on hand. (In the diagram above, "A+" indicates a sufficient supply of that subassembly, "A–" indicates an insufficient stock.) Where adequate supplies are available, the assemblies are reserved for the order.

For each kind of subassembly not in stock in adequate quantities, manufacturing orders will have to be made up, but not at this point. For each such major subassembly, its minor subassembly requirements and parts requirements must be determined. This is done in exactly the same way as for major subassemblies, namely, by having the equipment selector separate out all cards for the minor subassemblies needed and parts needed which enter directly into the assembly as parts. Again the parts requirements cards are temporarily set aside while minor subassembly requirements are compared to their stocks on hand.

Should any minor subassemblies of which supplies are inadequate be in turn made from lesser subassemblies, the above process is carried through again. Finally all requirements are reduced to parts requirements. Then all parts requirements cards, including those set aside earlier, are brought together and the totals for each determined mechanically. Their requirements are compared to the stocks of parts on hand, and manufacturing orders are originated for all items whose stock is inadequate. (*International Business Machines Corp.*)

Moore, 1951, Figure 14-1, p. 340; also diagram only, Alford and Bangs, 1945, Figure 39, p. 231

Figure 4

COPICS system flowchart

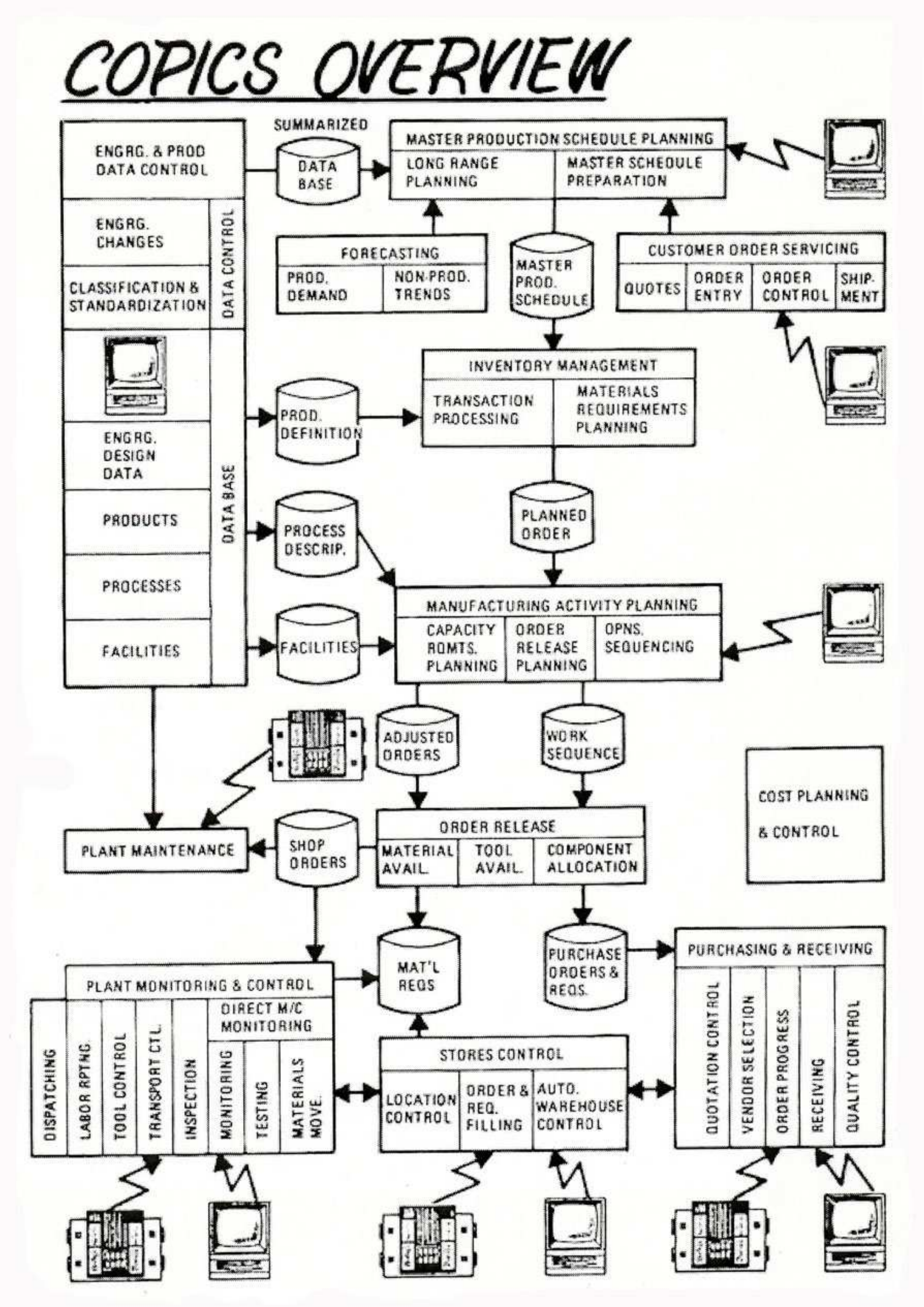

Figure 5

Systems flow chart

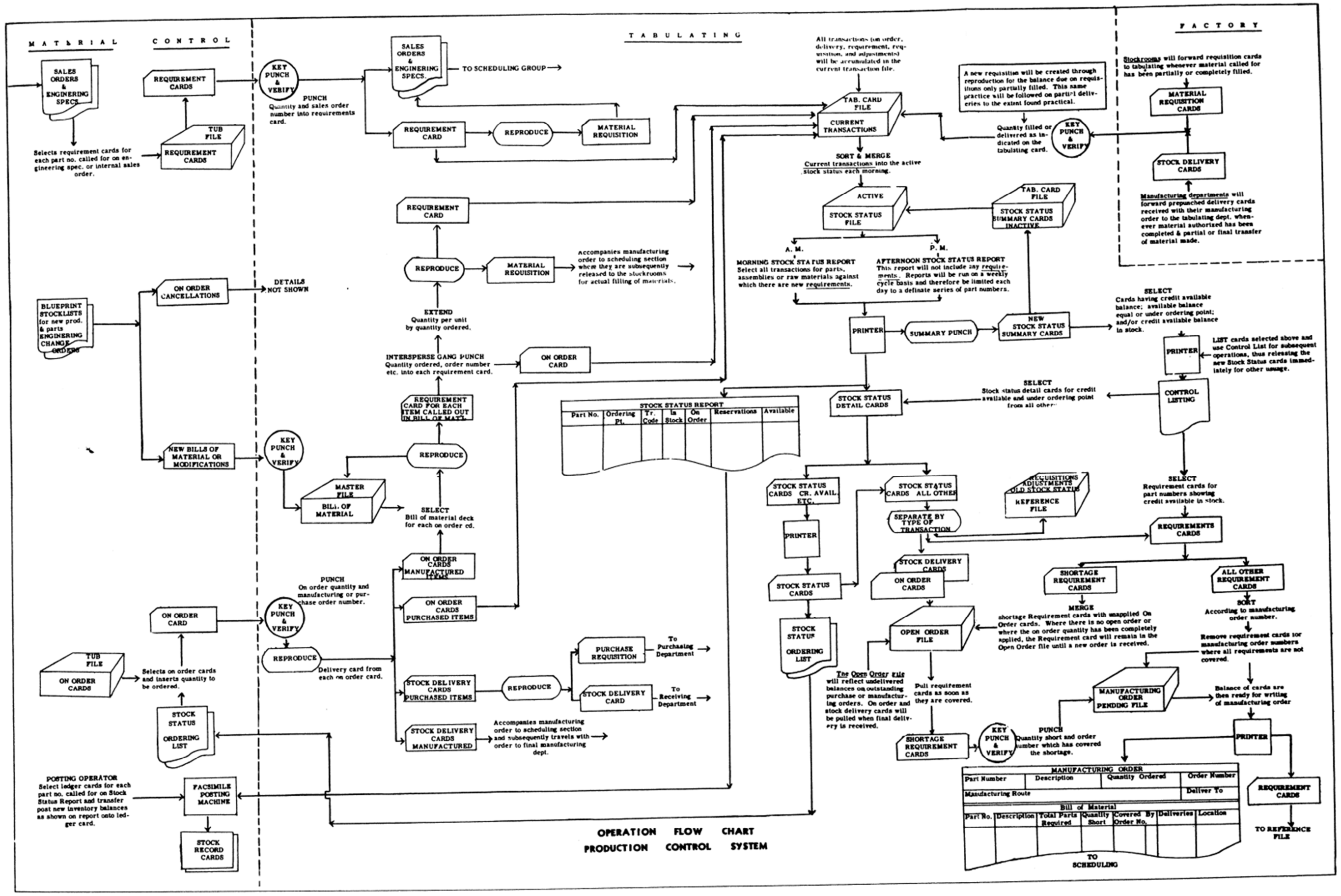

Fig. 14-1. Diagram showing the use of tabulating equipment in production control. The rectangles with cutoff corners represent the various cards used. Squares represent the use of the printer unit of the tabulating equipment, circles show the manual punching of cards, parallel lines with rounded ends indicate the preparation of cards mechanically. (*Automatic Electric Co.*)

(Moore, 1951, Figure 14-1, insert after p. 332)

Figure 6

Manual system flow chart 1

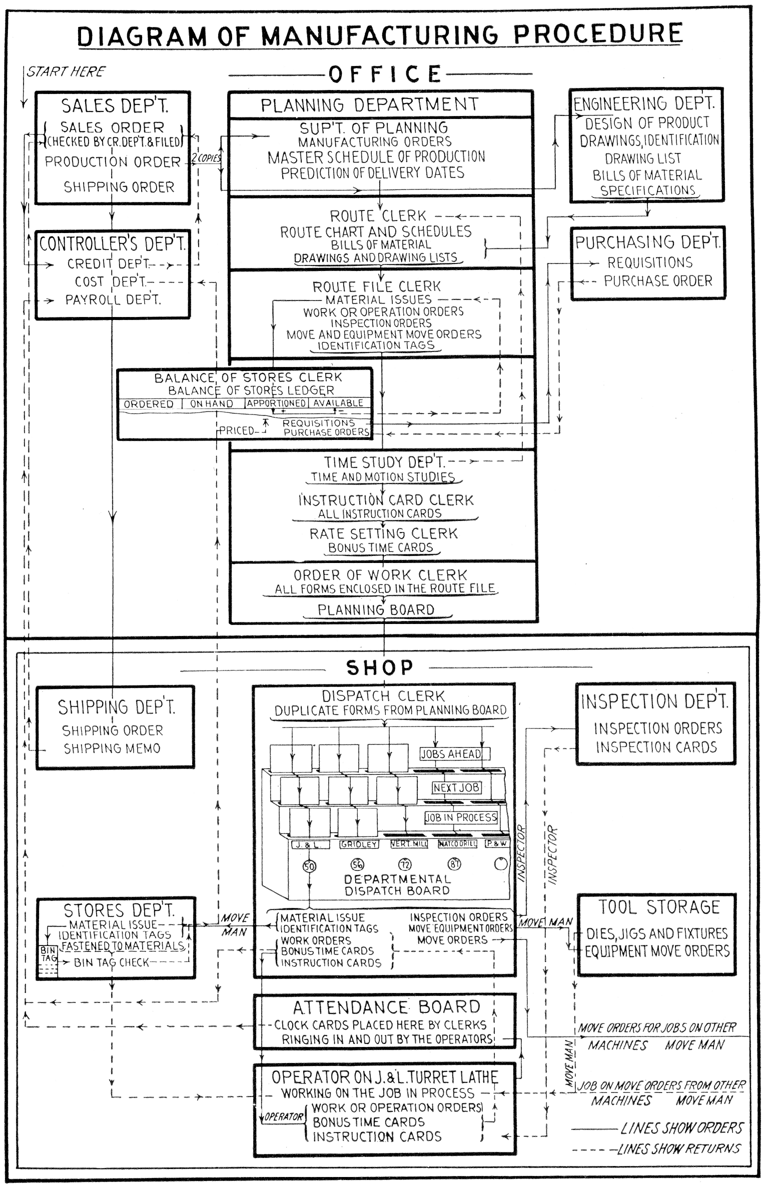

FIG. 29.—DIAGRAM OF MANUFACTURING PROCEDURE.

Kimball, 1925, Figure 19, p. 158

Figure 7

Manual system flow chart 2

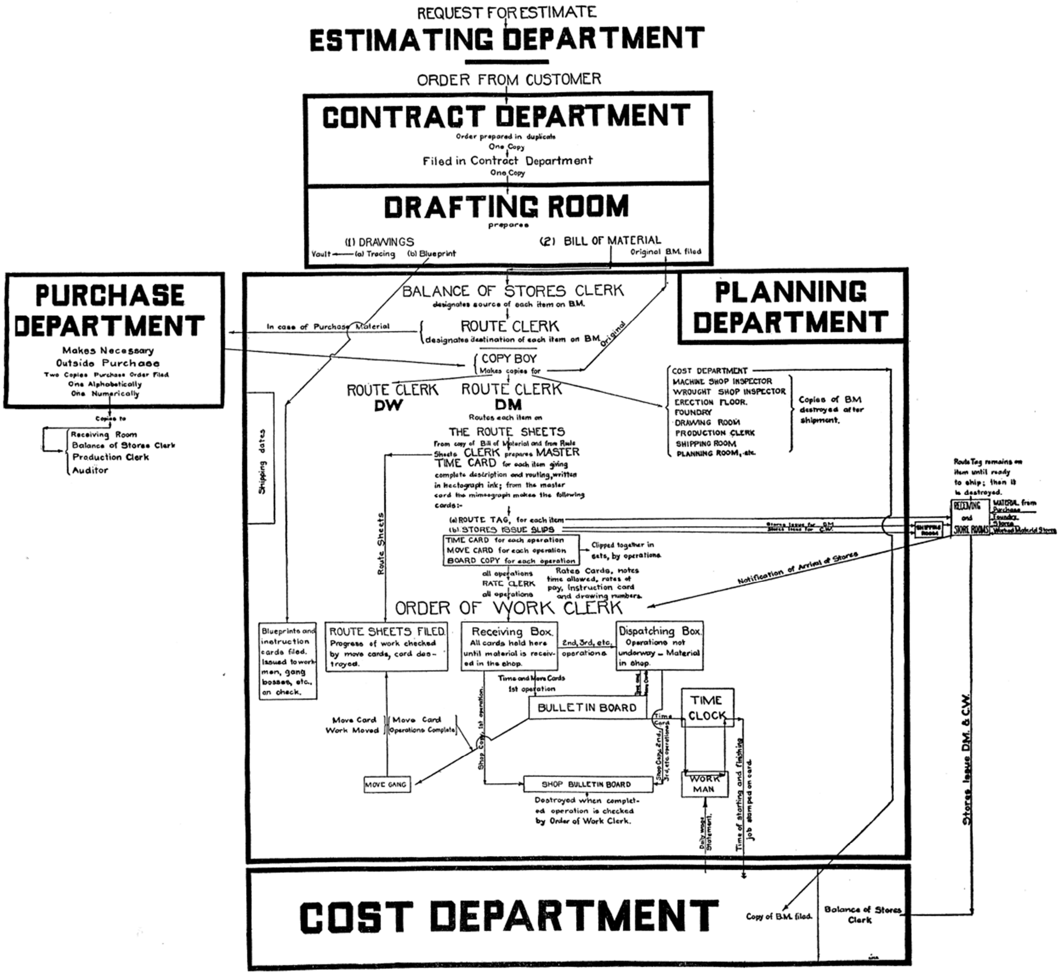

Chart II.

Sterling (1914, after p. 306)

Figure 8

Production planning tableau

PRODUCTION SCHEDULE AND INVENTORY CONTROL

Economic Production Program *3000* Lb
Mfg. of Economic Program Req. *10* Days
Batch Size *500* Lb   Min. Program *1500* Lb

Code Number *61267*
Product Name *XYZ*

	Jan.		Feb.		Mar.		April		May		June		July		Aug.		Sept.	Oct.	Nov.	Dec.
1 Estimated requirements for current month	1000		1000		1200		1500	2500	1500	3000	1500	2000	1200	1500	900	1000	800	800	800	1000
							These were increased on Mar.17				These were increased on May 24.									
2 Inventory on first of month – In process	2000	2000	1000	1000	–		–	–			1200	500				500				
Finished	5000	4625	5000	4625	5000	4625	3800	3425	2300	925	2600	2425	2300	925	1100	1925				
Total	7000	6625	6000	5625	5000	4625	3800	3425	2300	925	3800	2925	2300	925	1100	2425				
3 Est. prod. – No. 9 previous mo.	0	0	0	0	0	0	0	0	3000	5000	0	0	0	3000	1500	0				
4 Total of No. 2 and No. 3	7000	6625	6000	5625	5000	4625	3800	3425	5300	5925	3800	2925	2300	3925	2600	2425				
5 Subtract requirements for mo.	1000	1000	1000	1000	1200	1200	1500	2500	1500	3000	1500	2000	1200	1500	900	1000				
6 Calc. inventory, end of mo.	6000	5625	5000	4625	3800	3425	2300	925	3800	2925	2300	925	1100	2425	1700	1425				
7 Est. use for next 2 mo. If No. 7 is greater than No. 6, difference is prod. in No. 8	2200	2200	2700	2700	3000	3000	3000	4500	2700	2700	2100	2500	1700	1800	1600	1600				
	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.				
8 Calc. prod. for next mo.	0	0	0	0	0	0	700	3575	0	0	0	1575	600	0	0	175				
9 Schdl. prod. for next mo.	0	0	0	0	0	0	3000	5000	0	0	0	3000	1500	0	0	1500				

This row from sales forecast kept 6-months ahead.

Light face columns are calculated tentatively always for some period ahead (say 4 months.) This gives the theoretical amount of product needed.

Bold face columns are calculated from actual inventories on hand on 1st of the month which are available by the 5th. This calculation is made for the current month after the actual inventory is known.

Above calculations are for current month except as noted.

THE ABOVE PRODUCT CONSISTS OF THE FOLLOWING DIRECT CONSTITUENTS.

Sheet No. 1 of 1 Sheets

10	Jan.		Feb.		Mar.		April		May		June		July		Aug.		Sept.	Oct.	Nov.	Dec.
Code No. 9078 % 25							750	1250				750	375			375				
Name ABC																				
Code No. 8095 % 55							1650	2750				1650	825			825				
Name FGT																				
Code No. 7609 % 10							300	500				300	150			150				
Name CQ																				
Code No. 8323 % 6							180	300				180	90			90				
Name HT																				
Code No. 6214 % 4							120	200				120	60			60				
Name J H																				
Code No. %																				
Name																				
Code No. %																				
Name																				

Inventory available on 5th these columns are calculated on the 6th

Direct constituents are calculated from theoretical requirements for the product XYZ.

The percentage figure shows how many pounds of materials ABC, etc., are required for 100 lb of material XYZ.

See accumulation sheet for total requirements of material ABC as used in all products requiring material ABC.

Year *1948*   Group *Acid Blues*   Class *A B*   Product Name *XYZ*   Code No. *61267*

Koepke, 1949, 1954, Figure 7, p. 391; 1961, Figure 12.7, p. 151