Chapter 2
The Historical Foundations of Manufacturing Planning and Control Systems

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2.1 Introduction

Before probing the history of manufacturing control systems, we have to ask a question. What is a manufacturing planning and control system? In theory, there is a simple answer – it is a system of "things" that work together to control what is done where, by who, using what set of resources (machines, tools, and materials), at what time, and in what quantity. Controlling also implies setting expectations or knowing what the expectations are, measuring the realized manufacturing performance and outcomes, knowing what is where, what has been done, providing feedback, and making necessary corrections so that the expectations and goals can be met, or at least be better met in the future. So, what are the elements of a manufacturing planning and control system?

First, these systems include, or at a minimum are influenced by, the harsh, physical reality of the plant–machine layout (functional or process), machine and tooling capability, inventory locations, space around machines, and material movement options. The physical or technological aspects provide potential options for, and constraints on, what can and cannot be physically done in the plant, and thus provide a form of *physical manufacturing control*. Flexibility can exist in the physical components and can range from different fixtures to physically altering machines (combining or separating). Exploiting any potential flexibility in the physical system may have associated costs, lead-time issues, and risks.

Second, superimposed over the physical reality are the logical components – policies and procedures. The policies and procedures, if at all accurate, can never overstate or violate the physical reality and usually act as constraints on the physical flexibility. For example, if the floor loading will support 10,000 kg/m^2, a logical policy allowing inventory to exceed 10,000 is nonsensical. However, a policy restricting the inventory to 8,000 kg might make a good inventory control policy independent of any economic order quantity. Policies and procedures may also be influenced by

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outside forces. For example, governmental rulings regarding health and safety might also constrain the degrees of freedom. The set of applicable policies and procedures used by a firm form the *procedural manufacturing control*. Depending on the nature of the issues they address, some policies and procedures have latent elasticity and thus constitute relatively soft constraints which can be negotiated based on the business context.

Third, between the procedural and physical manufacturing levels, there are the actual tools and instruments used for control – *manufacturing control technology*. This includes *monitoring and informing* techniques for knowing what has happened, where things are, the status of work orders, as well as *activation and notification* techniques for indicating when work should start, how much should be produced, or where inventory should be moved to. For example, barcode readers and sensors can determine the production results at a machine, and a Kanban card or signal can indicate that production can start on a particular item. The manufacturing control technology also includes the *logic and analysis* behind all of the production control process for determining what is needed when and what is the best way of doing it. Included in this subcategory is the MRP logic, planning, scheduling and dispatching tasks, and so forth.

To summarize, a manufacturing planning and control system will combine the following elements:

- Physical manufacturing control
- Procedural manufacturing control
- Manufacturing control technology – monitoring and informing, activation and notification, and logic and analysis

While it is possible to think of these elements as being reasonably independent, they become interrelated and interdependent during manufacturing execution. For example, in the 1920s a form of mechanical scheduling using conveyor systems as a controlling mechanism was described (Coes 1928). Everything was moved by conveyor – if there was something on the incoming conveyor and your machine was not blocked by the outgoing conveyor, you performed your task. If you were starved or blocked, you did no work. This controlled the total inventory in the plant and forced machines and operators to an idle status. There was no inventory outside the conveyor system. This is very similar to the effects of Kanban and illustrates a combination of the physical, procedural, and technology components.

If all three elements are appropriately matched to the manufacturing situation, it is likely that manufacturing will be efficient and effective. If one or more of the components is significantly inappropriate to the context, then manufacturing is more likely to be chaotic and definitely not efficient or effective. For example, expecting a job shop to respond effectively and efficiently to a Kanban pull from multiple assembly areas without adequate bins and quantities to cover the variable lead time that will result is an example of a mismatch. Another mismatch arises when inventory control techniques such as order point are used when the majority of work is composed of dependent demand and the demand is highly variable. This also does not work well. Thus, a goal of manufacturing system design is to know what form of manufacturing planning and control is suitable for a given level of quality, volume, speed of manufacturing, and mix. The design challenge is compounded by the fact that requirements will undoubtedly change over time – the three axes represented by the procedural, physical, and control elements must be periodically reviewed to ensure that balance is retained. A common example of requirements evolving over time is an increase in product variety with a decrease in volume for each product type. Depending on the magnitude of each change, the situation may flip from a high volume, low mix situation to a low volume, high mix situation, which might warrant layout changes accompanied by changes to manufacturing control.

As we review the history of manufacturing planning and control systems, these elements and their interplay will be used to anchor the discussion. Section 2.2 will provide a brief history of manufacturing planning and control systems prior to the start of the twentieth century. Section 2.3 will focus on the early systemization and developments during the first three decades 1900–1930. Section 2.4 will look at the situation in the 1950s, 1960s, and early 1970s. In this chapter, we will not focus on the physical shop floor execution systems that sense and track the actual production, but on the logical controls using this information.

2.2 Pre-1900

Before 1900, there were isolated examples of relatively large-scale, systemized manufacturing concerns which involved various types of manufacturing control. For example, Lane (1934) describes the fifteenth century Venetian Arsenal. The arsenal had a moving assembly line for the rapid completion of galleys. In the early 1700s, the Lombe brothers constructed a large-scale silk mill in Derby (Cooke-Taylor 1891) and by the end of the 1700s, Boulton and Watt had collaborated at the famous Soho Manufactory (Doty 1998, Immer 1954). The Portsmouth Block Mill of the early 1800s (Wilkins 1999) and the American armouries of the same time period (Smith 1977) also introduced manufacturing control innovations. In each of these examples, high volumes of products were manufactured with little logical manufacturing control per se; the majority of control was imposed by the layout and physical nature of the plant. There was little competition and in the case of the military units, the focus was on basic production and not on the efficiency and effectiveness of the manufacturing process. Lombe and Boulton/Watt also had business structures similar to that of a monopoly and while manufacturing was controlled, extreme levels of transactional analysis was not needed. By the 1830s, the concepts of quantity and economic production were being discussed (Babbage 1832).

Starting in the mid-1800s, manufacturing activity expanded rapidly (Hounshell 1984) and by the late 1800s manufacturers were looking for ways of reducing the chaos. The American Society of Mechanical Engineers (ASME) started to publish a number of papers and discussions of manufacturing management and techniques in the late 1800s. As the most thorough and thoughtful treatise on the matter, Lewis (1896) might be the first manufacturing management text. Lewis provides a very thorough discussion and mapping of a factory's decision making and information flow, details the cost accounting, and describes how manufacturing was orchestrated from order taking to shipping. While others such as Taylor (Kanigel 1997) focused on a subset of manufacturing management, Lewis described the whole organization. This was a British publication, and no equivalent North American publication appeared for at least two decades. We have been unable to find a reference to Lewis' work in any of the early Industrial Engineering texts. Generally, any systematic form of control and organization was an exception and as noted by Emerson (1909), the general state of manufacturing was mass confusion and the first order of business was to systemize and bring some order to the process. The systemization of manufacturing would prove to be challenge.

2.3 1900–1930

During these three decades, the manufacturing sector saw the mass systemization of production and associated activities (McKay 2003). There were many articles and publications written during this period covering an immense range of topics (Cannon 1920). Subjects included what individual operators were doing and how to supervise them (Taylor 1903, 1911), incentive schemes (Gantt 1910), how to organize resources in functional and process arrangements (Diemer 1910, Kimball 1913), mass production and continuous improvement (Ford 1926), focused factory organizations (Robb 1910), economic analysis of inventory (Erlenkotter 1989), supply chain management and hand-to-mouth inventory (Nash 1928, Alford 1934), statistical process control (Shewhart 1931), and reconfigurable production lines (Barnes 1931, Koepke 1941). As noted by Alford (1934), the majority of manufacturing activity was relatively basic and did not require or use many of these ideas. There were, however, occasional exceptions. The idea of just-in-time inventory (hand-to-mouth) was widely used in the 1920s. For example, Nash (1928) had daily turns of inventory at his automotive assembly plant and there were many examples of lean supply chains and controlled inventory. Throughout industry there were many assembly lines and material handling devices deployed, but there was little evidence of large numbers of companies actually using statistical process control, economic analysis of inventory, or other algorithmic types of procedural or logistical manufacturing control. Knoeppel and Seybold (1937) pointed out that in general the prescriptions, tools, and concepts created by the early Industrial Engineers were rarely used.

It appears that the majority of manufacturing management effort was focused on tracking and basic control. Almost a century later, this reasoning still appears to be the primary reason for firms implementing ERP systems and this will be discussed in later sections. Even in the early 1900s, the physical and control technology was rudimentary and was composed of the typical functional, product and process flows combined with basic book-keeping. There were many self-help style publications on how to codify parts, organize tools, and have smoother flow of goods through a factory. These were still popular topics in the early 1930s even though they started to be discussed in the early 1900s. One of the most common topics throughout this era was that of tracking and planning boards. Gantt's 1919 work is perhaps the best known of the graphical display methods, but there were others such as Knoeppel (1915, 1920) who was a consultant like Gantt and proposed a variety of ways to present, plan, and track work through factories. In this period, many mechanical planning boards and production control tools were developed to help plan, track, and predict factory operations (Simons and Dutton 1940). There were also many card and filing systems created to account for and to track production, some using IBM's punched cards (Simons and Dutton 1940).

In terms of procedural or logistical control, very little of a mathematical nature can be found before mid-century. There was the work on economic order quantity (Erlenkotter 1989) which was adopted by some portion of industry, but it is hard to ascertain how popular the method was or who actually benefited from it. Other mathematical techniques were applied to quality control, especially sampling (Robertson 1928a, b), and control limits (Shewhart 1931). Based on descriptions found in American Statistical Association (1950), it would appear that statistical tools such as sampling methods were used extensively in the World War II production effort but not before. This is supported by the minimal reference to SQC/SPC in popular texts of the time (e.g., Koepke 1941). There was substantial work on forecasting, of course (White 1926), but this was not really of an operational nature as it focused on the longer term. For actual planning and scheduling, very little mathematical analysis was proposed to help with sequencing decisions. This is not in itself surprising since the manual effort to mathematically analyze any reasonably realistic industrial scheduling problem would have been prohibitive. Knoeppel (1915) recommended using a numerical ratio to determine the best time to start a subsequent operation when overlapping tasks, which is the only example of a scheduling or dispatching heuristic that can be found from this era. Note that this dealt with the operations within a job and not really sequencing multiple operations on the same machine. There is no solid evidence that anyone used his suggestion. In texts dedicated to routing and scheduling (e.g., Younger 1930), there is no mention of advanced reasoning beyond that of looking at overlapping operations for better sequencing and the body of the texts are focused on creating departments, systemizing paperwork, setting up basic plans, and tracking. The only other "advanced" algorithmic suggestion found in the literature related to work flow through a factory. Knoeppel (1920) suggested that work should be pulled through factories using an approach not unlike MRP and this message was still appearing in 1940 publications (Simons and Dutton 1940).

2.4 The 1950s, 1960s, and early 1970s

In the era before the wide-spread use of computerized MRP, a factory with even a modest amount of product variety and process complexity found that they had a very difficult planning and scheduling task. Koepke (1941) describes one factory using approximately thirty people to generate a 2-week plan. It took them 2 weeks with overtime to prepare the next 2-week plan. The amount of paperwork and manual effort was just daunting. It is little wonder that the majority of manufacturing used statistical, order point or quantity reordering schemes which were independent of actual orders or demand even as late as the early 1970s (Orlicky 1975). As Orlicky comments, given the information systems they had, it was the best they could do. Orlicky estimated that there were approximately 150 firms using MRP-type systems by 1970 and that this number would grow to 700 by 1975. Part of this increase was expected by Orlicky because of the MRP Crusade mounted by APICS in the early 1970s. This slow evolution from the first business computer usage for inventory management and control in the early 1960s to this awareness in the early 1970s was considered a major development.

The elements of MRP are now well known. There are bills of material, time-phasing concepts, calculating component item demand, lot sizing, estimation of coverage, priority control, and load projections. A key concept in MRP was clearly distinguishing dependent demand based on end item forecasts and orders from independent demand such as that arising from component sales and service parts. Plossl (1973) identifies an article by Orlicky in 1965 that describes the independent and dependent demand principle as being the breakthrough development. Hopp and Spearman (2001) provide a very good description of how MRP works and the subsequent migration to MRP II. In MRP II, the integrated computer system pulled together the additional functions of "demand management, forecasting, capacity planning, master production scheduling, rough-cut capacity planning, dispatching, and input/output control" (Hopp and Spearman 2001).

Interestingly, the basics of an integrated MRP were described and actually implemented in the early part of the twentieth century (Knoeppel 1915) and the number of clerical staff required can only be imagined. This early MRP system had almost all the key features of the later computerized systems: bill of material, routings, backward loading of work with lead times from shipping (or required) dates, finite capacity loading and analysis and *daily* updates, and was also used to provide availability information to sales. Unfortunately, the issues later commented upon by Orlicky became the reality for the people who recognized the benefits arising from a more integrated planning approach. To do any systemized and thorough manufacturing control process required a great deal of dedication and effort. This might be the reason why no other integrated MRP-type systems with a short horizon can be found in the literature for the next 50 years – examples or concepts. Knoeppel's factory example and system description appears as an anomaly.

How were the 1970s reached? The first computer was sold for business purposes in approximately 1954 (Orlicky 1969) and the traditional areas were pay-roll, sales analysis, accounting, and cost analysis (Reinfeld 1959). Reinfeld points out that the adoption of computers into production control was very slow with only a few companies doing it (e.g., large aircraft companies, General Electric, and a few others) and that the majority of applications were mostly listing and posting. Computers were still very expensive in this period and it is not surprising that few were used and that production control was performed with little black books and what could be found in the head of the foreman (Reinfeld 1959). Even by 1973, Plossl (1973) was estimating that less than 1% of the computer base was being used for manufacturing and he speculated that there were two main reasons: first, suitable applications did not exist that would actually do the job, and second, production and inventory control personnel did not see the need for such a system in the first place.

Before continuing the MRP discussion, it is useful to step back and consider the general order point approach and what was happening. The statistical order quantity or order point was being used for almost every type of manufacturing by 1970. This was not always the case. Plossl (1973) describes a version of material requirements planning that had been done quarterly in many firms (e.g., tool building, ship building, aircraft, locomotives, and other heavy products). Unfortunately, "As product models proliferated and as the product complexity increased, however, it became increasingly difficult to develop a practical, workable production schedule for finished products far enough in advance, explode all of the bills of material, net out available stocks, and trigger replenishment orders. The work of making the calculations and record comparisons was too time-consuming, the technique was impractical for products of even moderate complexity without the use of a computer." (Plossl 1973, p. 69). This led to over reliance on the independent demand techniques. We of course know that independent demand techniques can and do work quite well in the right situation. Manufacturers in the 1920s (McKay 2003) and Japanese firms later in the century figured this out. If you can stabilize the forecast for a reasonable period of time (e.g., 6 weeks $\pm$ 10%) and balance your production capacity accordingly, you can use very simple production control methods, the most famous being Kanbans. The Just-In-Time approach is, in essence, an independent demand order point system. Unfortunately, this does not work well in many other situations.

Plossl's comment is interesting in that the 1950s started off as a very simple production environment. The Anglo-American Council on Productivity 1949) noted the few models and minimal options provided by American manufacturers and the British writers compared this to the proliferation of parts and high-mix facing the British counterparts. Koepke (1941) describes a variety of different master schedules, each depending on the type of situation. For example, in mass production where almost everything was dedicated and connected by moving conveyors, chains, and other mechanical devices, the master schedule was considered the schedule for the final part as everything else just flowed together and did not need to be scheduled, At the start of the second half of the century, the situation was relatively simple for the large manufacturers operating in a mass production mode. For projects or intermittent production, Koepke described master schedules that synchronized components and sub-assemblies using a bill of material and there were other master schedules as well. The focus on safety-stock between final assembly and the customer, and the general dismissal of upstream uncertainty fits the idea of dedicated lines with low variety operating at high volumes. Simple order points would suffice for materials and small parts in mass production settings and the quarterly ordering method described above by Plossl would satisfy the project-oriented production. If a functional approach, and not a product layout, was used for mass production the result might have been different. If the mix was low, resource conflict almost non-existent, and there was not much re-entry, the functional layout would behave like a virtual flow line and not require sophisticated planning. However, the functional layout would not have been a difficult physical control concept to plan and orchestrate for mass production when high-mix existed and resource and material conflicts arose.

By the 1970s, production was no longer simple. There were many models, many options, and manufacturing was getting messy. It was no longer possible to have dedicated and duplicated equipment for each end product, and it appears that many firms adopted a functional factory style. Automotive plants were the exception as they continued to use drag-chains and main assembly lines. Functionally organized factories found that the order point approach was not successful at controlling inventory (avoiding stock outs or minimizing inventory throughout the plant). If the existing functional layout and basic manufacturing execution control was to be retained, the basic MRP approach was the perceived answer.

The various assumptions and difficulties associated with the traditional MRP approaches are eloquently explained in Hopp and Spearman (2001). The key issue relates to the way that lead time is used independent of the plant status. Because of this assumption, MRP can model and plan a dedicated, automated line with high reliability – the bottlenecks cannot float, work cannot enter or exit the line, and everything is predictable (within limits). The large, drag-chain automotive assembly lines once common in the industry are examples where MRP was relatively successful. If you have a job shop, or free-flowing virtual assembly lines with highly variable loading, MRP cannot estimate when anything will be used or produced. Another assumption is that the model of the process and product is static and stable over the planning horizon. There are usually some records and some fields in MRP which have effective date controls, but the majority of the production model is static and if the factory is rapidly or constantly changing, the model is inaccurate. An inaccurate model results in infeasible planning and expectations. MRP systems can also exhibit nervousness and sensitivity to changes in the forecast or production results. The generated plan can ask for different quantities and dates every time it is created. This is not a problem on a resource that can react quickly. However, if there are infrastructure issues (e.g., the resources needed to set up the machine, additional helpers, etc.) or supply issues (e.g., cannot easily change the schedule at a steel mill) the nervousness can be annoying. Ongoing nervousness can also result in increased errors and problems as the plant tries to do what the plan asks for.

In its approach to inventories, MRP is reactive – it will try to maintain certain levels of finished goods, work-in-process, and raw. MRP logic does not typically include strategic use of inventory that will allow the level to go below the level specified. For example, it might make sense to make more of one product and less of another during a short horizon because of situational factors and then recover to the desired levels a bit later. This type of reasoning and commonsense is absent. The final limitation of MRP we will note is that of inventory bank health. By this, we mean the degree to which the right parts are in the bank in the right quantities to minimize conflicts on machines and to space out (e.g., cycle) production. If there is a significant disturbance in the factory that upsets this balance, how does the factory recover to the desired levels of inventory for each part that avoids conflict? Often the human is expected to review the plans each day and make the necessary adjustments – increasing the quantity of one part, decreasing the quantity of another, locking in dates etc. MRP does not have the tools or the ability to determine whether the inventory is not in balance and how to recover, and it is not possible to do it manually in a realistic industrial environment.

Taking all this into account, it is sufficient to say that MRP was not the answer to all manufacturing situations and was unwisely applied to a number of situations. The MRP and MRP II approach has always relied upon a number of assumptions and unless they are satisfied, grossly infeasible schedules and plans will result. There are assumptions about the type of manufacturing system being applied to, and there are assumptions about how the MRP system is actually used. If there are too many resource conflicts and manufacturing execution is highly variable, the amount of manual intervention to resolve exceptions and conflicts is immense. Since sustained attention to such issues has proven to be difficult for almost all firms, MRP- and MRP II-based systems (e.g., ERP systems) have remained problematic whenever the manufacturing environment is less than ideal. The efforts to combine advanced planning systems with MRP logic is an attempt at bridging some of the gap and associated difficulties. By including finite modeling, more feasible schedules can be attained and if things go well, the results will be better than guessing.

2.5 Conclusion

It has become a historical and sometimes hysterical truth – if the various components of manufacturing planning and control are well matched to the environment, things will go well, and if they do not make sense, chaos and mayhem will dominate the milieu. Use MRP type concepts in a situation either not suitable or without the discipline and matching philosophy, and you will get what others have got before you. Use Just-In-Time concepts incorrectly and you are unlikely to get the Toyota halo-effect. As the mix and volumes change in products, so must the manufacturing system. This includes the physical, logical, and technological. Historically, it can be seen that the basic ideas for good production control were known and advocated in the early 1900s, but the technology required for effective, sustainable implementation did not then exist.

In the second half of the twentieth century, manufacturing was focused on what they could do with the information systems they had and this rapidly changed when computer-based systems became widespread. This change coincided with the problem changing from one of simple mass production to that of complex mass production and more functional layouts. Once MRP-based systems started to be popular in the early 1970s, manufacturing was then focused on MRP as the solution for all manufacturing problems and became momentarily blinded to other concepts. Periods became locked in, inventory checked in and out of stores, and expediting and chaos became routine. The models and varieties continued to increase and then competition appeared that make simpler products with very few options. This competition was able to flow material through factories, with many inventory turns a year and without complicated planning and scheduling. Toyota was able to do in the later stages of the twentieth century what the North American manufacturers once were capable of doing. Nash and others might have been amused.

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