A GENERIC CONCEPT
OF A MANUFACTURING SYSTEM
FOR VARIOUS PLANNING AND EXECUTION SYSTEMS

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ABSTRACT:
We propose a general framework to study planning systems. By reconsidering the basic planning decision variables, we show that an Advanced Resources Planning (ARP) approach can be the fundament for many, yet any, planning system. ARP is the result of a mathematical model of the manufacturing environment and embraces quantitative performance measures as well as qualitative insights. We show the application of ARP to Material Requirements Planning, Just-In-Time, Lean, Theory of Constraints, Finite Scheduling, Load Based Systems, CONWIP and POLCA.

KEYWORDS:
Planning, Manufacturing Models, Queueing.

In this paper we like to address a concept of planning which goes back to the fundamentals underlying the planning decision. First, we outline the concept of planning in its three dimensions: time, material and resources. Subsequently, we explore this idea for various planning systems.

1. LEAD TIMES: THE CORE OF ADVANCED RESOURCES PLANNING

Given the above, a workable definition of Planning is defined along the time axis: *the decision in terms of positioning various events on a time axis to serve a particular objective*. A typical example is the release of an order (e.g. a production or purchasing order). The release moment is positioned in such a way that, given the nature of the system, the system provides timely and reliable delivery at the agreed due date of the order. The latter can be quantified in terms of the lead time. The above definition of planning falls apart in three basic dimensions, Time, Material and Resources. All three together they constitute the system for which the Planning is to be considered.

The first dimension Time is the time axis itself. It is a constantly increasing function, therefore often put horizontally on charts. It is a very easy dimension to define but that characteristic makes time extremely hard to deal with in planning reality. In the classic view of physics, Time has no degree of freedom, it just passes by. Time cannot be speed up or slowed down. In addition, Time can also never be recovered if lost. All these are important aspects of the planning issue, because if there are problems with respect to the time dimension (e.g. running out of time), the solution has to be found in the two other dimensions of planning discussed below.

The second dimension of planning consists of what can be named Material. Material are these objects of a system which typically enter the system, take temporarily part of the system and then leave the system. As such Material is typically of interest for the customer, and common performance objectives related to Material are lead time, customer service, quality, etc. Material flows and moves through the system. Examples are cars in traffic, patients in hospitals, visitors in the amusement park, customer orders, manufacturing orders, data transferred on the internet, e-mails, etc.

The third dimension of planning consists of what can be phrased as Resources. Resources are these objects of a system which are intended to remain in the system (at least compared to the Material). Resources are of interest with respect to the 'owner' or responsible of the system and therefore performance measures like utilization, productivity, efficiency will enter the picture. Examples are machines in a job shop, staff in a hospital, desks and staff at the airport, lanes and intersection in traffic, attractions in the amusement park, etc.

Of course, sometimes the line between material and resource is thin: what about the meals on the plane and the role of tape to pack carbon boxes? The meal seems to be material (to be assembled with the passenger, but with no further impede towards the flow) and the tape looks more like a resource (also to be assembled with the box but it may impede the flow when not available and cause waiting time for the Material, in casu the boxes). It may definitely depend on the typical case under study to make it up. However, our experience showed that in many cases this discussion can be easily resolved.

What's more important and relevant for the planning problem under study is that each planning problem always constitutes of these three dimensions and in order to be dealt with effectively, these three dimensions must be considered simultaneously. A good example of this intersection is what is known as scheduling. The output of a scheduling routine can be materialized in a gantt chart: this is the picture taken from the viewpoint of the resources. Each resource is listed and along the time axis all relevant events are posted at the right point in time. However, if the sequence of jobs is visualized, this shows the material viewpoint. For instance the lead time and the number of jobs late can be derived, two typical material characteristics. Scheduling problems are known to be difficult so in general, planning in itself cannot be considered as easy.

Nevertheless, popular planning approaches seem to position themselves outside this intersection. The reason for this may be that the intersection is indeed too complex to deal with and wiping out a dimension simplifies the planning problem. A well known example of this approach is Material Requirements Planning (MRP). By the sequential approach in terms of the material and capacity calculations (Capacity Requirements Planning is done after the lead time off setting), MRP is situated more in the intersection of the material and time. That's why capacity management is so hard with an MRP approach and subsequently, the lead times are neither correct nor realistic, with all the consequences known today (see for instance Suri and Hopp and Spearman for a detailed discussion on the bad sides of MRP). Other approaches like JIT or TOC 'behave' like they are in the intersection, but they assume that the underlying manufacturing model is readily available, which is definitely not true in many instances. Also Finite Scheduling is subject to input from the planning level (see e.g. Lambrecht, Ivens and Vandaele). Also the more execution-type systems like kanban, POLCA, Conwip and the like may benefit heavily from a well done planning exercise.

Advanced Resources Planning or ARP (see Vandaele and De Boeck, Vandaele) constitutes of a planning model based on these physical characteristics of the system and thus taking the three basic dimensions of planning into account simultaneously: time, material and resources. In the literature we typically observe queueing models for this purpose. A survey lies outside the scope of this contribution, but many open en closed queueing networks serve this purpose. A typical outcome of these models will be a lead time distribution. This lead time distribution is visualized in figure 1.

Figure 1; Typical Lead Time distribution.

It is this important performance information of a physical model of the manufacturing system, that feeds the planning decisions, whatever planning framework the system is subject to.

2. LEAD TIMES FOR PLANNING

We will sequentially touch some well known planning methodologies: Material Requirements Planning (MRP), Just-In-Time (JIT), Theory of Constraints (TOC), Load Oriented Planning, (LOP), Finite Scheduling (FS) and execution systems like CONWIP and POLCA.

2.1 MATERIAL REQUIREMENTS PLANNING

Material Requirements Planning may be considered as the most widespread planning methodology these days with a huge number of software solutions to integrate this planning logic in the overall business processes of the firm: the ERP (Enterprise Resource Planning) approach. Although its basic planning features have been developed in the 1960's, the planning core of the current ERP systems is basically the same. Consider the simple example exposed in table 1.

Time	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Table																				20	
Leg															80	80	80	80	80		
Surface						20	20	20	20	20	20	20	20	20	20	20	20	20	20		
Box						20	20	20	20	20	20	20	20	20	20	20	20	20	20		
Screw						320	320	320	320	320	320	320	320	320	320	320	320	320	320		
Tube		X	X	X	X	X	X	X	X	X	X	X	X	X							
Cap		80	80	80	80	80	80	80	80	80	80	80	80	80							

Table 1: ARP and MRP.

The simple product is a table, built up of four legs, one surface, sixteen screws and one box for packing. A leg consists of a steel tube of length x and a rubber cap. The table is assembled inside and takes one day. The legs are also fabricated in house and this takes 5 days. All other components are externally sourced and the delivery time is 14 days for surfaces, screws, boxes, tubes, and caps. In order to show the basic MRP logic, we simplified the MRP tables drastically to the summary shown in figure 'explosion-table'. In this table the following information is provided: Suppose there is a commitment to ship an order of 20 tables on day 30, the final assembly and packing should take place on day 29 as indicated by the table. In order to able to do so, all components of the first level in the bill of material should be available at the beginning of day 29, or conversely at the end of day 28. This holds for 80 legs, 20 surfaces, 20 boxes and 320 screws to be available at the end of day 28. Given the lead time information on the components, screws, boxes and surfaces all take 14 days to order and be delivered. So they are ordered at the beginning of day 15. For the fabrication of the legs, they are released at day 24, so that at the end of day 28 they are available for final assembly. In this way day 24 provides a due date for tubes and caps. Both are ordered at the beginning of day 11, so they will be available at the end of day 23 allowing for fabrication of the legs. Although this is a very simplified view on MRP, it illustrates the very basic flaws of it. The ultimate flaw is that MRP uses fixed lead times which will turn into non realistic material and capacity plans. This can be symptomized along the following issues:

- MRP is a <u>sequential</u> approach: first material plans are generated and sequential capacity checks, not simultaneously as discussed in section 'planning'. As a consequence, it is always a (ever) recurring procedure in the hope for convergence… It is known that this is neither efficient nor effective. On top it is very nervous: a small change in either the material or capacity plans, may cause a course of iterations in the MRP planning logic.
- MRP is a <u>deterministic</u> approach: once set into the system, the lead times are what they are. They do not provide a means to take into account the stochastic nature of lead times and assume a zero/one approach: the operations can always be processed with certainty within the specified lead time off-sets. There is no dedicated guessed safety time employed.
- MRP is a <u>static</u> approach: the lead times do not change in terms of changes in load or managerial decisions like for instance lot sizing. Changes in demand like seasonality, product mix shifts, new introductions, phase outs, and the like are not taken into account. In the same way, vacations, shift patterns, outsourcing decisions among others are mostly neglected. Even more importantly, managerial decisions in the area of changing customer service levels, selling policies, lot sizing etc. urge for a dynamic view of lead times.

As we assume along the lines of the Advanced Resource Planning approach, the above mentioned aspects should be reflected in the lead times, then these lead times might be used to provide more realistic lead time offsetting information. In this way, it should be clear that if a typical MRP system is provided with this more realistic lead time information, the usability and applicability of the current MRP/ERP systems is leveraged to a great extent. This is one way to get the investment in an expensive ERP system get paid back. Vandaele, Lambrecht, De Schuyter and Cremmery illustrate the potential of this approach. See also Suri for the discussion on the 'High-Level-MRP' and Hopp and Spearman as both are describing a similar concept as introduced here.

2.2 LEAN - JUST-IN-TIME

Whereas MRP effectively wants to provide a plan for material and capacity, JIT and Lean Manufacturing depart from a different assumption. The flow of material must be organized in an efficient way so that an easy execution of the flow is possible. In our discussion it means that at the planning level, flow must be provided in such a way that detailed planning can be avoided and can be reduced to an execution system like kanban. All operations are lined up to provide flow production and the materials enter at the point of use, like the caps in the example. Lean means here that the lead time for performing an operation must be short and reliable, as discussed before. Therefore, (just) enough capacity must be provided so that the demand in terms of the load always can guarantee this short and reliable response, sometimes phrased as tact time. This discussion is basically the same as the one for MRP; the only difference being here that in the case of JIT, in order of magnitude, tact times are definitely much shorter than the MRP lead times. This typical for flow oriented systems as their primary objective will be throughput. Ensuring a short and robust tact time involves an evaluation of the load on the tact time and typically employs more capacity (than a comparable MRP driven system) or consequently, a lower utilization. This uncomfortable side effect of JIT/Lean can be countered with 'waste' avoidance. In our discussion, this turns into lower stochasticity levels in terms of more stable demand and/or more process control. Also lower variability levels are on focus: better quality, six sigma, better maintenance, setup reduction, etc. All of them are issues which are typically considered as JIT/Lean prerequisites. At this point our lead times insights can be of great value. The above described ARP approach can be used a scientific underpinning of the more practical approach of lean manufacturing.

2.3 THEORY OF CONSTRAINTS

The approach taken here is the primary focus on the constraint or bottleneck of the system. The bill of material is further detailed in a bill of manufacture (bill of processes), specifying for each component what operations are involved. Along these lines, the load is compared with the capacity of the system. Subsequently, the constraint is identified and planned in detail. The execution of the TOC system is described as Drum-Buffer-Rope. Drum stands for the schedule on the bottleneck. Assuming that chroming is the constraint operation in this example, the schedule on the constraint must be pampered to stand through time. This can be done by providing a buffer in front of the bottleneck. This buffer can be provided by releasing material early enough, so it arrives early in the bottleneck buffer. So it eventually boils down to a release decision, which is a time based decision. In order to synchronize non-bottleneck operations to act in line with the constraint planning, the release of material is organized in such a way that bottleneck operations are protected (constraint ropes), assembly operations are protected (assembly ropes) and that shipments are protected (shipping ropes). This is illustrated in table 2.

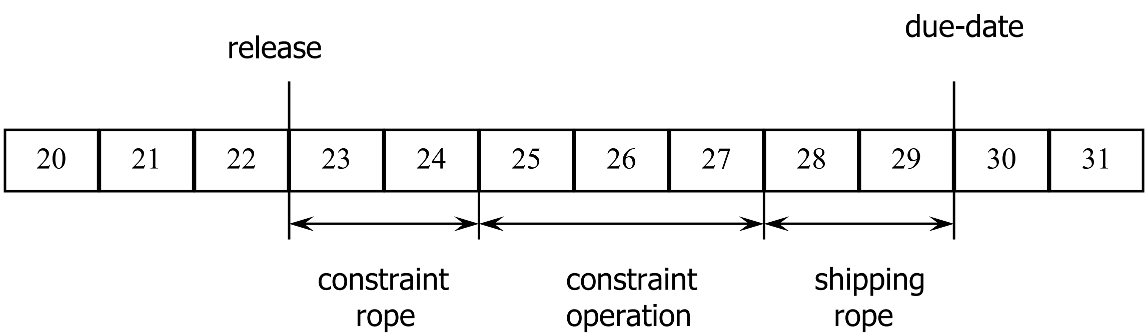

Table 2: ARP and TOC.

It should be clear that providing a safety time is the way in which a rope is to be settled. Ropes are lead times, and have all characteristics discussed above. However, the TOC does not provide a systematic way to set lead times and work with them dynamically. ARP insights can be of great value here.

2.4 FINITE SCEDULING

Finite or detailed scheduling is what traditionally is defined as scheduling: assigning material (job operations) to resources, sequence them and provide start and end times of all job operations respecting capacity constraints and precedence constraints. The output of this endeavor is typically represented in a Gantt chart as shown in table 3.

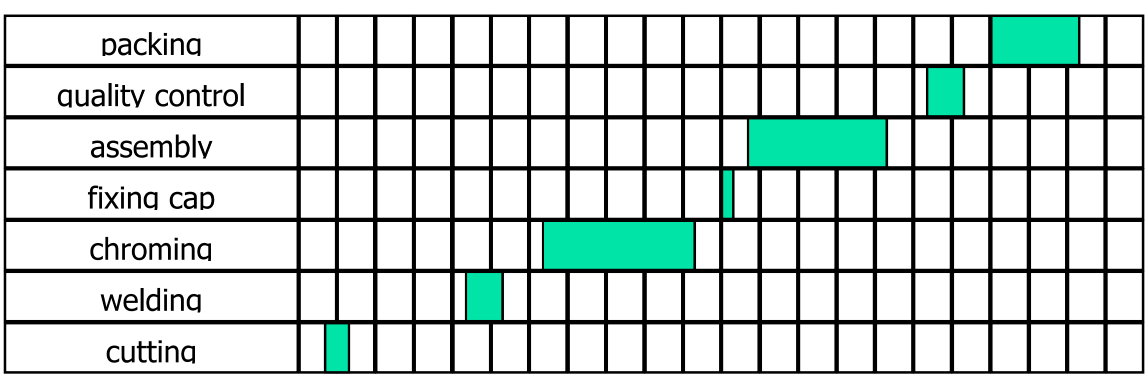

Table 3: ARP for Finite Scheduling

We will not elaborate on the scheduling issue itself but we can assume that for realistic problem sizes scheduling is computationally hard. What is important for our discussion here is scheduling systems do not provide important parameters themselves. A scheduling system assumes release dates and due dates. In most of the cases, also lot sizing decisions should not be the issue of a scheduling system. These are planning parameters and should be prepared to in order to facilitate the scheduling effort. It is clear to see that if for given due dates, the release dates are too late, or for given release dates, the due dates are too tight, then the scheduling system cannot come up with a good solution. It means that if the time windows are too tight, the work cannot be accommodates in the offered windows. On the other hand, if the windows are too loose, then the detailed scheduling will not encounter many problems. This is however misleading: it means that lead times are unnecessarily long and could be shortened so that a shorter lead time (and less inventory) yield the same performance. In other words, if the planning parameters at the ARP level are well done, then the scheduling effort will be much more successful and reliable. Establishing the windows to feed detailed scheduling is again nothing else than good ARP practice taking into account the dynamic and stochastic nature of lead times. We refer for instance to the ACLIPS approach (Lambrecht, Ivens and Vandaele).

2.5 LOAD BASED EXECUTION

This is a whole family of approaches where the major idea is only to dynamically release material along a limit criterion. If the current material plus the intended release of material does not meet a pre-specified limit, then the intended material is released. If the limit is reached, then the release shuts down until the criterion is met again. The criterion can take many shapes: work content measured either in units, in hours or even in monetary terms. There are many examples of this approach:

- Load Oriented Planning: Here the load is expressed in hours, which are discounted for more remote operations in the routing. It is typically suitable for job shop environments.
- CONWIP: CONstant Work In Process (see Hopp and Spearman) puts a WIP cap on the system. In terms of execution it relates WIP with Throughput of a system.
- POLCA: This is a capacity based extension to the generic kanban system.

Without going into the details, these methodologies all benefit of a good physical modeling where load is based on one or another lead time estimation, which is transformed into wip, hours or work content.

3. CONCLUSIONS

In this paper we showed how physical models can be applied in practice by providing the necessary planning parameters. These parameters are set so that the system on hand in under control. Many systems may benefit: MRP, JIT, TOC, Finite Scheduling and Load Based systems.

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