Manufacturing Planning under Uncertainty and Incomplete Information

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Abstract

Real world evolves in an uncertain and unpredictable manner. This statement can be fully extended even to the case of a collaborative effort of multiple manufacturers driven by common goals. Throughout the century, the world of manufacturing has changed from a mainly "in-house" effort to a distributed style of production. Final products became more complex. Stiff competition, high level of specialization, vast differences in the labor force and many other factors led to an enterprise production style with outsourcing a significant number of jobs and services. For some of the industries, the production coordination requires to consider more than hundred suppliers of services or sub-assemblies.

In a diverse, heterogeneous, distributed manufacturing system, planning becomes the cornerstone of the overall success of the enterprise. This fact has been overwhelmingly recognized both by the manufacturers that view new intelligent planning systems as another revolution in the manufacturing world, and by software vendors of Enterprise Resource Planning (ERP) and Supply Chain Planning (SCP). However, to support uncertainties and dynamic changes of the real world, such a planner should be at least efficient and reactive.

Many manufacturers are interested in timelining their activities for two or three years in advance. Some of them account several hundred thousand different products and many more intermediate inventory items throughout such a long time horizon. Thus, manufacturing world faces the problems of resource allocation and constraint satisfaction of huge sizes. Modeling principles are expected to digest oceans of data and output a feasible, executable plan or detailed schedule within a reasonable amount of time. Simple investigation shows that manufacturing modeling is more than 30 years old, it was probably the state-of-the-art design for the tape-drive computers. By now it should have been re-written, but the inertia of the field opposes new approaches, because none of them proved to be fully functional for all manufacturing scenarios.

Both uncertainties and dynamic changes are essential features of the real world. To produce realistic plans or schedules, a manufacturing planning system should take them into account. In this paper we discuss the main modeling principles of manufacturing planning that got derived through more than 30-year history of the area and real applications. We state the assumptions and the simplifications that traditional manufacturing modeling does in order to maintain a reasonable balance between the modeling expressiveness and the computational power of planning tools.

Introduction

Modern World has emerged a new era of mass customization. This trend is changing the way customers are making purchases, it also has a strong impact on how products are made. Known as on-demand manufacturing, it spans already a diverse set of manufacturing areas from luxury cars, to computers, books and toys just to name few. Actually, the greatest recent stories of success are directly associated with the ability of the vendor to satisfy customers on an individual basis without jeopardizing prices and delivery terms.

Traditional, make-to-stock manufacturing world is undergoing a significant transformation too. In recent years, an increased competition, changing economic environment, and new government regulations have conspired to put pressure on process plant margins. Computer components, for example, decline in value at a rate of about one percent a week. In such an intensive environment, the key test for the system is to ensure that the right products are delivered to the right place at the right time. This test determines the whole suite of requirements for planning, scheduling and execution systems that constitute the back-end of a customer-oriented manufacturer.

The software market offers next to nothing to support reliable quoting and planning for on-demand manufacturing. Although most of the users prefer a single automation software supplier, they cannot justify the reduction of the number of vendors they deal with. Many do not believe that any one existing vendor can provide a fully functional suite of best-of-breed applications. Dell, non-arguably one of the most successful on-demand manufacturer in the extremely volatile personal computer market, employs a symbiosis of Glovia and i2 software to support the required functionality. However, when it comes down to complete sequencing, detailed scheduling and execution, everybody is on their own.

What are the reasons behind leaving several multi-billion market niches almost completely untouched? First of all, it can be explained by the absence of tools that would enable producers to handle order promising and job-floor scheduling efficiently enough for the on-demand type of environments. In the vast majority of cases, "efficient" does not mean just "taking less time to compute," very often it is the matter of "life and death", i.e. the probability that the scheduler outputs a feasible, optimized solution based on the previously given quotes is dangerously closer to zero than to one. Secondly, big guns of a production automation business like huge Enterprise Resource Planning (ERP) houses (SAP, Oracle, PeopleSoft, Baan, J.D.Edwards, Lawson, QAD, etc.) and even Supply Chain Planning-oriented companies (i2, Manugistics, Numetrix, Logility, etc.) seem not to consider customers with revenues less than $200M/year. Thus, the whole brunches of on-demand industries can be easily overlooked because of their fragmented nature.

Current state of manufacturing modeling is several dozen years old. Earlier Manufacturing Resource Planning (MRP) systems had to find a compromise between the modeling expressiveness, computational power and slow access to peripheral devices, such as tape-based memory systems. Although MRP itself was viewed as a "Copernican Revolution" (T.E.Vollmann, W.L.Berry, & D.C.Whybark 1992), it has been identified that the current "state-of-the-art" manufacturing modeling used in MRP does not support anymore the growing need in providing efficient grounds for the enterprise level of integration. The main question to be answered with respect to the modern state of computer equipment is as follows: "Why is the product structure's file segmented into the BOM and Routing files?" (E.Goldratt 1990).

The inertia of the field keeps the above splitting principle untouched for old projects, as well for newly launched ones, thus adding even more to the inertia's spinning momentum. However, it is becoming more and more obvious that such a modeling approach has certain limits, especially when applied to on-demand style of manufacturing. For example, 1,000,000 different books ordered through Amazon.com would require 1,000,000 different Bills of Materials (BOMs), even though the majority of their components are exactly the same.

On the other hand, Artificial Intelligence (AI) has evolved as a mature discipline, capable of solving a variety of realistically sized planning and scheduling problems. AI systems consistently defeat human players in checkers, we recently witnessed first victories of AI-based chess playing programs against the world champion. AI systems have gained a definite advantage in computationally intensive problem domains. Whereas previous successful implementations of MRP systems were relying primarily on Operations Research (OR) tools, for example Linear Programming, there are more and more successful examples of AI-based solutions (ILOG, i2, PCorder, etc.). AI has accumulated enough knowledge to be applied across different engineering areas in a non-traditional manner. Manufacturing modeling, planning and scheduling definitely provide a rich and responsive testing field for innovative AI technologies.

Eli Goldradt, a leaving classic of manufacturing planning, identified the current manufacturing modeling system as obsolete (E.Goldratt 1990), even when we speak about classical planning driven by forecasts and actual sales orders. The requirement of reactive, on-demand architecture completely rejects existing approaches. How well are companies surviving the transition? The answer is - with pain. ERP systems are notoriously known as "root channels" of manufacturing corporations. Ad-hoc solutions do not scale at all. Usually the back-end is buried under a mysterious cloud of a non-comprehensible complexity that scares away even the most courageous programmers and computer analysts. Thus, a latest shift from selling a standard suite of products, from a make-to-stock production to mass customization has added new tough requirements on order processing and quoting, on production planning and demand planning.

Traditional Assumptions in Manufacturing Modeling

Traditional Manufacturing Modeling has gone a long way towards finding a reasonable balance between the expressiveness of the modeling processes, realistic nature of models themselves and the computational power (the convergence) of planning and/or scheduling tools. Real world evolves in an uncertain and unpredictable manner. It is even more veridical in the case of on-demand manufacturing. Simplifying assumptions had to be made to enable manufacturing automation software handle thousands of products and production processes stretched over a several year time horizon. In this section we state some of them, mostly the ones relevant to dealing with uncertainties of the real world, the ones that have the most impact on the process of planning and scheduling.

Resources

Two types of resources are recognized in manufacturing. Reusable resources (machines, operators) may be re-used multiple times throughout the considered timespan. Consumable resources (raw materials, inventory items) become the part of the product, correspondent quantities of them should be available before a production task is started. Sometimes consumable resources are allowed to be produced or delivered incrementally, so that the consuming task is planned to be intrinsically synchronized with a task or tasks that produce that resource. During the execution the quantities are consumed and should be replenished before the items can be consumed by other processes.

Recently a new type of resources has been considered by the supply chain planning community. If a supply chain model includes a conversion of intellectual property ino a physical matter, then a third type of temporal resouces is introduced. This type of resources is activated at a certain point in time by the conversion and remains reusable until it becomes obsolete. Table 1 shows all three types of resources.

Resuable Resources	Consumable Resources	Temporal Resources
Machines Operators	Raw Materials Inventory Items	Intellectual Property Converted into a Physical Matter

Table 1: Types of Resources.

Durations and Lead Times

One of the cornerstone assumptions in traditional manufacturing modeling is that production tasks have fixed lead times and durations. For example, when a vendor is planned to deliver raw materials to be used in sub-assemblies of the product, the delivery process is assumed to take the same amount of time, whether it falls on weekends, national holidays or normal weekdays. Thus, a pre-specified amount of time becomes a fixed lead time for the specified vendor.

In general, manufacturing modeling identifies three ways of building up inventory. Inventory items can be produced, purchased or transferred from another place. Both purchase options and transfer options have individual lead times that do not depend on the quantity of items specified in these options. However, effectivities and order modifiers may influence the way how both options are applied.

Duration of a production task depends on the quantity of produced items. Each production task requires a set of reusable resources and a set of consumable resources. A common assumption is that one of the reusable resources is the primary resource, its rate determines the duration of a task in a linear fashion: A task has a non-negative (possibly zero) set-up time and the duration of the task grows linearly on the quantity of items to be produced.

Effectivities

Throughout the considered timespan, many predefined parameters are allowed to change their values. This assumption is enforced in an off-line manner. Before applying planning or scheduling procedures, the sequence of parameters' values should have been predefined completely, as well as exact time periods where those different values are effective. Such an assumption seriously affects the complexity of deriving feasible plans or schedules for manufacturing environments with plenty of variable parameters. For example, the definition of a primary resource can change over time, thus the duration of a production task can be different depending on the time this task is planned to be executed. Even worse, a different yield factor for a production task imposes the requirement of changing the quantity and, hence, the duration of this task.

In several months the entire list of components can change dramatically. For example, electronics became one of the areas that forces its manufacturers to upgrade products on a regular bases. A broad variety of components and the re-configurable nature of customized products add another twist to the complexity of planning and scheduling. However, effectivities became one of the essential sides of the trade-off that supports more realistic modeling expressiveness, even though it significantly complicates planning and scheduling.

Order Modifiers

Order modifiers is the main tool of manufacturing modeling that allows to reflect uncertainties of the real world. Order modifiers comprise of four major components:

- Minimal quantity,
- Maximal quantity,
- Multiplying quantity,
- Yield factor.

Many production tasks or purchases from an outside vendor obey the minimal or maximal requirements for the quantity of inventory items this task can handle. Usually, minimal quantity varies from one to several hundred, the same is true for the maximal factor. There is a strong sense in establishing these constraints. Since the execution of purchase orders of the same item from the same vendor takes a predetermined fixed lead time, there should be a reasonable item's quantity limit within which this vendor can produce and deliver the entire quantity on time. Furthermore, many production processes can produce only a fixed amount of quantities at a time. This is the way the multiplying quantity comes into play. In addition, for the simplicity of accounting purposes, purchases and transfers are often processed under the restriction of the multiplying factor, i.e. purchase or transfer orders can be executed with pre-specified increments in quantity.

Yield factor is the key player in planning production processes under uncertainties. If a product or an inventory item is new to the market or production, the yield factor of correspondent production task(s) is low, which means that bigger portion of this item's production fails and outputs scrap. Over time, the crew is gaining experience with this item or product, certain parameters of the equipment are better tuned towards producing this item, hence, the yield factor grows. During a physical delivery, an item can be spoiled, damaged or stolen, therefore, both a purchase order and a transfer order may have non-trivial yield factors.

Thus, the yield factor of order modifiers constitutes a simple way of modeling uncertain actions in manufacturing. Previous experience of manufacturing novel items of similar types sets expectations for the amount of failures on early and later stages of the production. These expectations are transformed in scalar yield factors, thus, featuring the yield factor as the cornerstone off-line modeling element of representing uncertainties of production processes.In conjunction with effecitivity modeling, the yield factor provides a simplistic heuristic guidance that navigates the planning process.

Planning and Scheduling

Manufacturing distinguishes planning and scheduling. Usually planning stands for aggregate planning, where the considered time period is fragmented into time buckets like shifts, days, weeks and months. Aggregate planners place production tasks into one or several consecutive time buckets without assigning start and end times. The proper sequencing of tasks that arrives from the producer-consumer relation, is weakly enforced, i.e. a consuming task cannot be assigned to a time bucket that is earlier than a producing task's one, but both tasks can share the same time bucket. In this form, aggregate planning is equivalent to bin packing with alternatives. Bins correspond to all reusable resources and appear repeatedly one per resource per time bucket. The capacity of a bin corresponds to the aggregated (per shift, day, week or month) capacity of a correspondent resource. An inventory item can be potentially produced in several alternative ways, with each alternative one routed through different resources, hence, contributing to different bins.

Detailed Scheduling enforces stricter relations between producers and consumers of the same inventory item than aggregate planning. All tasks are supposed to get start and end times assigned to them. The granularity of (detailed) scheduling is on the level of minutes, seconds or even fractions of a second. Additional constraints of certain types can be imposed to scheduling that are not applicable to aggregate planning, for example, the changeover constraint enforces a positive set-up (re-tune) time before the same machine can start producing items of a different type, the buffered supply chain constraint that requires a produced item to cool down for a pre-specified amount of time before it can be consumed by the next production process no earlier than it is too hot, but no later than it becomes too cold, etc. Scheduling is also supposed to obey detailed capacity constraints: If a machine can execute one production task at a time, then no two production tasks can be routed through this machine in an overlapping manner.

On-Line Re-Planning

In manufacturing planning, forecasts play the role of heuristic functions in guiding long-term production planning. Various statistical and Machine Learning methods are used to derive realistic forecasts, the automated process of constructing forecasts is also known as demand planning. Despite the fact that as heuristic functions, forecasts can be misleading, manufacturing community uses to follow such a guidance religiously.

Although manufacturing planning often spans a long period in time, any practical planner anticipates dynamic changes in the real world in a near future. While short-term production is mainly driven by actual sales orders, long-term production is driven at large by forecasts. Incoming, new sales orders can be deducted against existing forecasts or added as new requirements for the considered business unit. Whether derived from sophisticated demand planning modules, or simply reflecting the previous patterns of sales orders, no forecasts can precisely account for an exact demand a year forward from the planning moment. Thus, on-line replanning appears as a "must to have" feature of commercial manufacturing planners.

The process of manufacturing re-planning is in a certain sense similar to AI planning in a domain with dynamic goals. The actual manufacturing process is expected to undergo multiple changes upon receiving particular sales orders, thus, refining already planned production driven by forecasts. in the anticipation of those changes, manufacturing planners and schedulers usually arrange a way of adjusting forecasts upon getting actual sales orders. Incoming orders can affect existing forecasts (heuristic functions) through either deleting the entire quantity, partial quantity, re-arrange transfers between different business units, etc. Thus, the process of incorporating new sales orders into existing forecasts forms a flexible system of adjusting heuristic guidance in manufacturing planning.

Conclusions

When the Manufacturing Resource Planning (MRP) concept was introduced, manufacturers were very comfortable with the monthly granularity of planning. Manufacturers were used to have long lead times, and the performance was judged on the utilization of assets rather than customer service levels. The modern era of mass customization requires manufacturers to be much more responsive. Customers are now demanding planning accuracy on the level of hours, not weeks or days.

Manufacturing planning follows the guidance of forecasts to work around incomplete information. Whenever more specific information about the product demand is acquired, production plans are refined to reflect more precise knowledge about the real world.

Thus, the real-world development of manufacturing planning and scheduling came up with the following mechanism of resolving incomplete information: A projected demand stated in the form of forecasts drives the long-term planning process. Upon getting closer to the planned production time and receiving more detailed information about the goals, the production plans are refined in order to reflect more complete information about the goals. Therefore, realistic manufacturing planning is similar to AI planning that starts early execution and refines optimal solution policy upon acquiring more precise information about the planning domain with dynamic goals it operates on.

References

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