Vincent C.S. Wiers · A. (Ton) G. de Kok

Designing, Selecting, Implementing and Using APS Systems

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To Erik Maas, who possessed an unmatched capability to reflect on our work as APS consultants and who was able to give our work an ironical and cheerful twist.

—Vincent C.S. Wiers

To Irene, Casper, Merel, and Diede, gifts of life that made me grow as a person and who bore with me despite my absentmindedness from time to time, when struggling with understanding cause and effect in operations.

—A. (Ton) G. de Kok

Preface

Advanced planning and scheduling (APS) systems have been around for about 25 years and have seen widespread adoption in a large variety of companies. APS is often seen as an add-on of enterprise resource planning (ERP), but it is a class of a system on its own. Although the typical application of APS is in production systems, such systems are also applied in transport, personnel planning, and anywhere where resources need to be assigned to demand over time. Although APS projects are complex and costly, potentially have large business benefits, and at the same time carry a significant risk of failure, a standard textbook covering all aspects of implementing APS systems does not exist to our knowledge. In this book, we aim to discuss all facets of APS implementation, from theoretical background to design and the implementation process.

We will spend much attention on how APS structures can be designed, complementing existing production control concepts. We will discuss the role of APS versus the human planner. The process of making a design of an APS is presented, providing examples of typical design decisions that need to be made. We will also describe the process on how to implement and use an APS. We are not limiting ourselves to one specific APS technology or supplier; instead, we highlight the differences between types of suppliers. The differences between APS and ERP will be discussed on several places in the book, as the term APS is often used in conjunction to ERP—but very different in many essential characteristics.

The book will primarily be used to educate master students in industrial engineering. It is very likely that at some point in their professional life, they will be involved in an APS implementation or use. This book should provide guidance to them to select a suitable APS supplier, to make important design decisions, to organize the project, and to deliver results. Their understanding of APS should go beyond the main concepts—they have to understand how the concepts were formed and why a concept will work in practice and when not. This book aims to answer such questions.

As a secondary audience, the book can be used by practitioners in the field of APS. These can be consultants that select or implement APSs; IT experts that draw up business architectures, where APS is an element of such an architecture; or business process owners that are considering an APS implementation.

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Acknowledgments

This book is the result of years of writing, and it contains insights gathered during the better part of our professional and academic careers. Our motivation to write this book was that, to our knowledge, a comprehensive book on implementing APS systems did not exist. The first versions of the book were created back in 2005, and years later, when Ton joined the project, the progress of writing received a boost, which made finalizing the book possible.

When we started to lecture on APS systems together in 2012, to students it was not always clear what the relation was between the work of Ton and Vincent. Ton would represent the scientist who would approach planning problems with rigorous mathematics, and Vincent was seen as "the guy from practice," who would deal with planning problems in a pragmatic way. At the same time, students would see two bald guys that were enthusiastic presenters with a strong opinion. Writing the book has given us much insight on how these worlds interact: what can be learned from academia, what it actually means to apply theories, and what works in practice (and what not). So, in the course of the years, our worlds have come more and more together, and producing this book has also been an acknowledgment to each other's viewpoints.

We have been able to write this book thanks to the support of a number of persons.

We would like to thank the people at Quintiq for allowing Vincent to participate in a number of APS projects and to learn how planning in practice can actually be supported. Vincent has had the honor to work together with some exceptionally bright and capable APS experts at Quintiq.

There are several people who have reviewed draft versions of this book: Gudrun Goeminne, who has done a meticulous job, besides her busy job as a planning manager. Furthermore, we would like to thank Bram Bongaerts and Matthijs Toorenburg, who have also commented on earlier versions of this book.

Ken McKay has been an inspirator and a friend since 1996, when Vincent visited Newfoundland to discuss his research with Ken. Ken has given Vincent a head start in unraveling planning problems in practice.

For both of us, Will Bertrand has been a teacher and the architect of the current Operations, Planning, Accounting and Control group at Eindhoven University of Technology. Will's knowledge roots in the Golden Age of Operations, i.e., the late 1950s and early 1960s, when great minds like Herbert Simon, Charles Holt, Franco Modigliani, and John Muth combined forces to empirically study operations in factories; likewise Jay Forrester empirically studied supply chains. Will has been one of the few operations management researchers who spent a substantial part of his career in the industry to observe operational processes and the people executing and managing them. He has been able to translate these observations into concrete guidelines for developing control concepts. Since joining Will at Eindhoven University of Technology, Ton's mathematical modeling work to grasp the quantitative causalities in operations has taken Will's conceptual ideas as starting point and constraints. Similarly, Vincent's approach to conceptual problems in practice is rooted in the production control lessons provided by Will. We hope our combined efforts do justice to Will's legacy.

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Chapter 1
Definition and Context

1.1 Planning Environment

By planning, humans try to control reality, by simulating and influencing events that are expected to happen in the future. In planning something, humans will anticipate events that will or must happen, the time it will take for each event, and what preconditions and interrelationships exist for these events. Value networks are of particular interest here, as these networks – which we will refer to as supply chains, as this is the common notion used in practice and literature – need to deliver products or services against some expected timeline and reasonable costs. For many companies, an efficient and effective supply chain can be a competitive advantage, and planning plays a crucial role in achieving this advantage. This applies both to internal supply chains – e.g., "within the plant walls" – and external supply chains, between plants, warehouses, and customers.

Planning and scheduling (the term planning will generally be used in this book to encompass scheduling as well) have a large influence on the performance of supply chains. By utilizing capital intensive resources, assigning the right skills, and prioritizing customer orders, planning determines what operational performance a company will bring to its customers. At the same time, planning has not received much attention in practice for a long time. Humans that plan or schedule typically have not been selected or trained explicitly for the job and are most often not held in high esteem by their employers.

Analyzing planning processes and tasks is different from other tasks that are carried out in a company. Many tasks are "analysis" tasks – i.e., information is digested following a process and the solution is produced – for example, selection or categorization. Analysis tasks can be well described with flowcharts. However, planning tasks are challenging in the sense that they are "synthesis" tasks, meaning that a solution is designed from many elements and there is no one best solution, albeit many feasible ones. The solutions found in a planning task – a plan – are built up

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from a large number of elements that interact. Flowcharts describing synthesis tasks typically contain a few "boxes" with many inputs and outputs per box. These *black boxes* contain the magic of planning.

Furthermore, the world of the planner is continuously changing, as a plan made for today might not be valid anymore for tomorrow. This means that the time needed to create a plan is typically limited and replanning is more important than initial planning. Because planning tasks are complex, need to be performed under time pressure, and have a large impact on the operational performance of companies, a specialized type of decision support systems has emerged to support these tasks: Advanced Planning and Scheduling (APS). Implementing APS systems has similarities and differences with implementing other types of information systems. In this book, we will focus on the issues that make APS projects special.

Before Advanced Planning and Scheduling (APS) systems became available, decision support for these tasks was generally absent, apart from the self-constructed spreadsheets that have been created by human planning professionals. ERP (enterprise resource planning) systems have been implemented in many companies, and these systems are well equipped to carry out the administrative aspects of planning, such as the management of orders and inventories. However, ERP systems offer very limited support for the actual planning job – basically they produce a long list of things "to do" (e.g., production orders), and the human planner will have to make sure that these "things to do" can actually "be done," "will be done," and "have been done."

Initially, information systems for optimizing planning and scheduling were designed to use mathematical models, developed in the course of a century within the realm of operations research. Operations research has developed as a science from dealing with planning and scheduling problems in manufacturing and warfare. In the 1950s it was found that the uncertainty and dynamics in the environment of planners and schedulers create a mathematical challenge that prohibits the identification of an optimal solution. Optimality only exists within a rigorously defined mathematical model and assumes an unambiguous goal. In real life a planner faces multiple objectives, and any mathematical model fails to describe the alternative options available to her to steer toward a desired situation at some particular point in time. It is not a coincidence that in the 1950s Simon (1956) defined the notion of satisficing. Simon studied human behavior but also studied production planning and scheduling (cf Holt et al. 1960).

Unfortunately, operations research developed as a branch of applied mathematics, and most of the mathematical models studied are inspired by reality as opposed to empirically valid. By and large over 90% of the OR papers published assume perfect knowledge about the problem and its context. If (and only if) a mathematical model is included into an APS to generate a plan or schedule, it is a deterministic model. In this book we discuss the consequences of using deterministic models in an uncertain environment.

Similar to other new technologies, APS systems have brought many promises that have not been materializing consistently. A successful APS implementation means that the system is used and improves operational performance. Although success stories are easy to find, some APSs' use was eventually discontinued, and other implementation attempts have never succeeded at all. With this book, we strive for a higher success rate for APS implementations, by supporting human planners to achieve a better performance. This is why we also dedicate a chapter to the human planner.

1.2 What Is an APS System

1.2.1 Definition of APS

An APS is a type of information system (IS), but what makes an IS an APS? For some practitioners it might be obvious that APSs offer functionality to support planning or scheduling and they typically have graphical user interfaces. But this also goes for some ERP systems or modules or even a spreadsheet. Defining APS systems is particularly interesting in the context of ERP, as APS systems are often deployed together with ERP systems and there is a potential functional overlap between the two. Indeed, ERP suppliers claim to incorporate APS functionality in their ERP suite.

In this book, we will use a definition, which will not make a black and white distinction between APSs and non-APSs but will be useful for most practical situations. In short, an APS is an interactive planning tool, containing a model of a physical system, an engine, and an interactive Gantt chart. These elements are explained below:

(a) A *model* of a physical problem that needs to be planned or scheduled – i.e., decisions – have to be made regarding physical items or services that are generated in time with a certain quantity. The model can be represented as entities or objects with relations or in mathematical terms. The model can express planning tasks on the *allocation of capacity demand* (e.g., orders) *to supply* (e.g., machines, operators, trucks, materials) *in time*.
(b) An *engine* that is able to immediately recalculate the consequences on the plan of planning actions, imported data, or other changes to the state. APS systems typically do not need a batched or prolonged simulation run to recalculate, for example, job start times when another job is finished later or moved earlier by the user. This means that the user experiences an immediate response to a user action, which is crucial for effective system-user interaction. There is a gray area here though – in some systems, the propagation is very limited, and some systems basically offer any propagation that is required and which can be configured. The ability to immediately calculate consequences of actions depends on the size of the problem: when a user changes the sequence of one task, this is obviously easier to propagate than moving a set of tasks at the same time. Likewise, it is easier to propagate a single change in material requirements than to recalculate a material-feasible work order release plan across multiple stages in the supply chain.

(c) A *graphical interactive user interface* (GUI) that depicts the consumption of resources and materials over time. When considering allocation of tasks to resources over time, in nine out of ten cases, the GUI is an interactive Gantt chart. There are many forms of Gantt charts, but they share the characteristic of showing graphically task-resource allocations in time.

There are some more typical characteristics of APS systems, which we do not regard as necessary to classify a system as an APS:

(a) Potentially, *algorithms* (for a definition of the term, see Sect. 4.5.1) can be used to generate plans and schedules. Although this is typically offered by APS suppliers as functionality that can be implemented, the application of algorithms to real-life planning and scheduling problems is limited. It is a widespread misconception that an APS is basically the implementation of an algorithm that generates a plan or schedule.
(b) Typically, APSs store much information in *random access* or *volatile memory*[1] to enable fast recalculation of (parts of) the plan, e.g., caused by user actions. This can be seen as a more technical characteristic that is not immediately visible to the user; however, this technical characteristic enables an APS to be an interactive planning decision support tool.
(c) Another typical element of APS systems is that they often offer a much more *context-specific planning model* than ERP systems – the type of system APSs are often compared with. Being more context specific especially goes for the more detailed control levels such as scheduling. APS suppliers achieve this by having more focus on a specific class of planning problems or by offering modeling technology that enables creating very specific models.
(d) APS systems are focused on supporting a specific type of planning process and therefore are more *mono-disciplinary* in nature than ERP systems, which have a wide variety of users in different functional areas. APS systems are for planning and scheduling, i.e., allocating tasks to resources in time.

Other names for APS that are sometimes used are finite capacity planning (FCP) and supply chain planning and optimization (SCP&O).

1.2.2 APS Structure

In line with the above definition, every APS has a model (demand and supply in time), engine (propagation), and a user interface (Gantt chart). The picture below shows how these elements relate to each other.

[1] Random access memory (RAM) allows data to be read or written in almost the same amount of time irrespective of the physical location of the data inside the memory. This is in contrast with data that is written to, for example, a hard drive. This means that RAM data is much faster available than non-RAM.

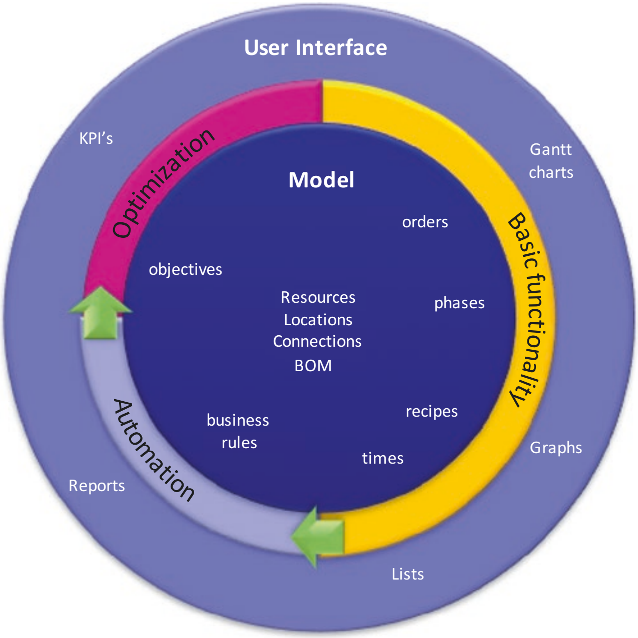

Fig. 1.1 APS structure (The layout of this picture is inspired by lecture material provided by J.C. Wortmann in the early 1990s, but to our knowledge, these models have not been published in scientific journals or books. This is why a reference is missing)

Figure 1.1 has been drawn with concentric circles to demonstrate that the outer circles can only work correctly when the inner circles have been implemented correctly. We would like to emphasize that:

> when implementing an APS, the initial focus should be on creating a good model of the physical world.

This is contrarily to a common misunderstanding that APS implementations are all about optimization and algorithms. The APS consultant needs to manage the expectations from the very start that creating a good model has a higher priority than implementing automatic planning and scheduling.

1.2.2.1 Model

At the core of an APS is a *model* of the physical world that needs to be planned or scheduled. A good model is complete, correct, and consistent and has the right level of detail. Technically, it can be an object model such as used in many information systems, where the object types and relationships represent elements in the real world. For example, there can be object types that represent machines, machine groups, routes, recipes, operations, products, materials, and the like. Some APS systems have a fixed model structure, which can be parameterized, and some APSs offer complete freedom in defining objects, thereby offering the possibility (and introducing the need) to design a model from scratch.

1.2.2.2 Functionality

The *functionality* of an APS is based on the model of the APS and offers the user the possibility to *do* things (actions, functions, methods) based on the modeled objects. We distinguish between basic functionality, automation, and optimization. Functionality that is used to import and export information from and to other systems is not included in this categorization:

(a) *Basic functionality*. Functionality can be used to perform relatively simple calculations, like translating volume into weight using a density. It can also calculate the consequences of planning actions, such as changing the sequence of an operation, based on a drag and drop action by a user. This functionality supports the user in checking *feasibility* of planning decisions.
(b) *Automation*. With automation, a set of actions (i.e., an algorithm – see Sect. 4.5.1 for a definition) is executed in the APS, to support the generation of a plan or schedule. Typically, the automation is triggered by the user in the user interface. But automation can also be triggered based on some other event or run according to a certain frequency.

Note that the distinction between these types of functionality cannot always be made unambiguously. In general terms, it can be stated that an APS with only basic functionality only supports the user in creating or changing a plan or schedule. All planning actions need to be carried out manually by the user, and the APS recalculates the consequences of these planning actions. An APS with automation typically can generate (a part of) the plan automatically, after which the user will make changes. Alternatively, a part of the plan is generated, where after the user creates the rest of the plan. For example, the APS carries out an automatic material reservation based on first come, first served, after the user has created a plan.

(c) *Optimization*. Algorithms that generate multiple possible plans or schedules and choose one according to some kind of scoring function are classified in this book as optimization. There are many optimization techniques described in planning and scheduling literature; however, only a limited set of algorithms are typically used in APSs. These are mathematical programming, neighborhood search, and path optimization algorithms. Automation and optimization are further described in Sect. 4.5. It is not the aim of this book to extensively describe planning and scheduling algorithms, as there is an enormous amount of literature on this topic (e.g., Dessouky et al. (1995) found 20,000 references to scheduling alone).

Implementing optimization is probably the most challenging part of implementing an APS, especially on the lower planning levels (see Sect. 1.2.4), and it should be done with great caution and specialized skills – see Sect. 4.5 for a more elaborate discussion. Typically, optimization is better suited to create plans on higher planning levels than the more detailed planning levels, such as scheduling. The reason for this is that scheduling problems contain many more details and the fact that operations in a scheduling context have a sequence, which makes modeling the problem much harder.

1.2.2.3 User Interface

The first APS systems – such as the German Leitstands, which translates into "control posts" – were basically Gantt charts visualizing production database content: scheduled orders and operations and their progress. In the evolution of APS systems, these Gantt charts have become interactive, meaning that the user can manipulate the plan or schedule with actions done in the Gantt chart – for example, dragging and dropping an operation in order to change the sequence on a particular machine.

Gantt charts can be implemented in many ways, but we define Gantt charts as having the following common elements – similar to how they were defined by Gantt (Gantt 1919, Organizing for Work):

(a) They are two-dimensional charts.
(b) On the horizontal axis, time is represented.
(c) On the vertical axis, resources are listed.
(d) In the chart, rectangles represent the work planned or scheduled on the resources.

The following picture gives an example of a Gantt chart for production scheduling.

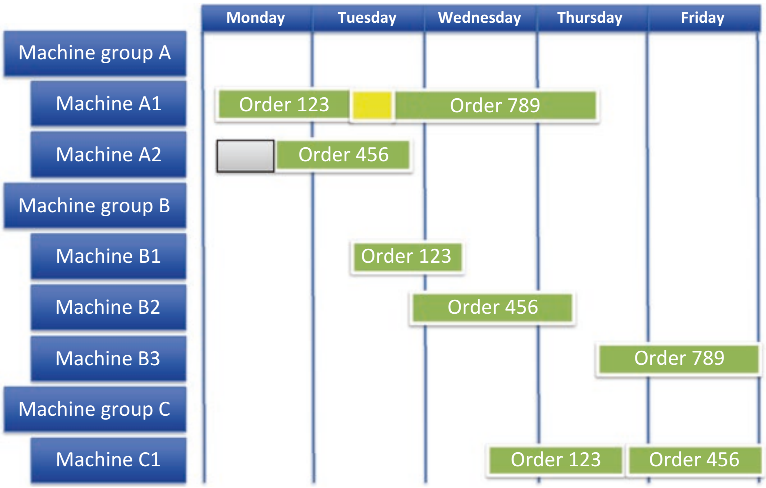

Fig. 1.2 Example Gantt chart for scheduling

Figure 1.2 shows that many elements of the scheduling problem can indeed be visualized, such as the grouping of machines, the sequence of operations of an order, the type of relationship between the operations of an order (end-start without a time lag in the example), the routing of orders, the setup time between two operations on the same machine (between order 123 and 789 on machine A1), and a calendar downtime on machine A2 (before the first operation of order 456). In a typical APS, the user would be able to change the plan by dragging and dropping the jobs – for example, to change the sequence or to change the assignment of an operation to a machine.

A variation on the Gantt chart is given below, which is more aimed at higher planning levels (Fig. 1.3).

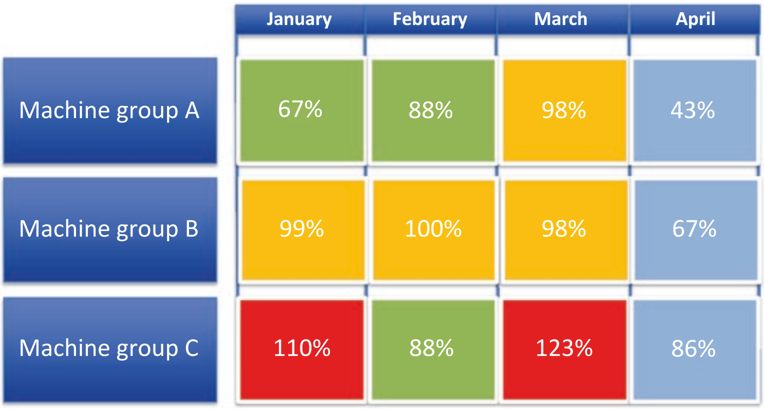

Fig. 1.3 Example bucketed Gantt chart for planning

The above Gantt chart does not have continuous time, but instead time has been represented in discrete periods. Periods can be referred to as buckets, as every time period on a resource represents a bucket of capacity. Such Gantt charts are typically used on higher planning levels, such as Master Planning and Sales and Operations Planning (S&OP). See also Fig. 3.10 where the difference between planning and scheduling is explained.

Although Gantt charts are a powerful technique to visualize planning information, not all information in APSs is represented graphically: all APSs also use lists to display information. Furthermore, many APSs offer the option to display information in graphs to, for example, show an inventory level (see Fig. 1.4). Key performance indicators can also be shown in graphs or in some kind of dashboard which is shown in a fixed area of the screen, so the user can immediately see the results of a planning action.